

## **SINGULARITIES, SOLAR SYSTEMS, AND SENTIENT LIFE**

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### **A CHRONICLE OF THE COSMOS CLUSTER**

#### ***Knowledge and Its Limits***

The challenge was this: How to put the universe in a nutshell?

How to take 160 just-out-of-high-school, mostly (sometimes even proudly) science averse students from the Big Bang to modern humanity, from the first light of the universe to the fading prospects of rapidly dying ecosystems, in one short year? How to put them on a first name basis with quarks and homeostasis and cladograms, so that they feel at home speaking the language of the cosmos? How to teach them to read spectral lines in starlight, radioactive tracers in rocks, fossil tracks in mud—so that they learn not only what is known, but how it came to be known, and why anyone (they, especially) should believe it?

And that's the easy part. They need also to understand the unreasonable effectiveness of equations (theory) in revealing hard truths, the astonishing power of simple (and not so simple) observations in overthrowing seemingly “obvious” facts; the impressive successes of the scientific method; also, its blind spots, its failures.

Yes, we really do know with great certainty what the universe was up to when it was barely a fraction of a second old. No, we still don't know the first thing about what the universe is made of--except that the vast majority of its energy and matter is unknown stuff entirely unlike ourselves.

Yes, we do know that every living thing on Earth descended from a common ancestor; we can put our fingers on fossils left by the 3 billion year old bacteria that exhaled the atmosphere we breathe today. No, we don't know, precisely, how any particular species come to be or what the future holds for ours.

#### ***Setting the Stage***

From the first lecture, the students get a sense of what's in store—as well as an introduction to the fact that their professors are on the front lines on this enterprise.

*I can remember each of the professors standing up there, and I was struck by the fact that these were leading scientists in their fields, standing here in front of a bunch of freshmen, and they were so passionate.... I felt so welcomed. It was the first experience in my education where a teacher has said to me, there's this whole world out there that's really interesting. You may not be able to understand the mathematics of it, but I want you to know about it, because it's so cool.*

—GE70 alum

One professor shows X-ray images he took of a black hole in the center of our galaxy—burping after a meal; also baby pictures he studies in his role as stellar obstetrician, peering through infrared “goggles” into thick, cold clouds to see stars turning on in dust-shrouded nurseries. Another tells how he gets rocks from space to tell him stories of their origins, how he “interrogates” specks of star dust. A third is an expert on carnivorous beasts; she explains what the mechanics of the kill can teach us about evolution: there's a lot of detective work involved, based on careful measurements of teeth, holes they leave in skulls, scratches left by gnawing. It's more than a little overwhelming. Following along with the story of the universe requires, at minimum, physics, astronomy, geology, life sciences—all in enough depth to instill a minimum fluency, all with enough breadth to invite connections each field with the next, each epoch with the other, so it doesn't seem strange, after a

while, to trace the origin of a particular shape of a beak of a bird on the Galapagos Islands to the motions of continental plates powered by the slowly leaking radioactivity of atoms that got crammed with energy during a supernova explosion billions of years before our solar system was born.

*When I describe (the course) to people, it sounds crazy. It sounds too ambitious. But I think we've found a recipe that works. When our students leave our class, they have an enormously expanded context for seeing themselves and their place in the universe.*

—Astronomer and cluster coordinator Mark Morris

### ***First Steps—The Birth of the Universe***

It begins at the beginning, not only with the Big Bang but with the ABCs, the vocabulary students will need to understand how we know “what the universe is doing,” as Morris puts it. This involves some basics of electromagnetic radiation (light) and quantum mechanics; some simple forces and ingredients, like “sticky” quarks and long range gravitation. It’s not much to learn, a few simple concepts, but it’s enough to forge some simple atomic nuclei. It’s also enough to make it abundantly clear that galaxies all around us are speeding away from each other, faster and faster the farther away they are. Until at the far reaches of the universe, violent “quasars” are speeding away from Earth at a healthy proportion of the speed of light. “Those quasars are really hurtling,” says Morris.

But wait, one might well ask. How can we know that? After all, our own little solar system is hardly standing still. Sitting on a Merry Go Round that extends beyond the planet Pluto, we are spinning around the Milky Way, falling toward the galaxy next door, speeding along with the local flow of galaxies to who knows where. “We’re movin’!” says Morris. So how can we possibly hope to sort out, from our hardly-steady perspective, how much of the motion we see is “ours,” how much of things outside? How much is reality? How much illusion? What do these terms even mean from the standpoint of science?

This question, “How do we know?” is one of the themes that anchors the cosmos for students, ties the frequently strange goings-on “out there” to the thoughts and perceptions “in here,” inside our heads. It’s a process of thinking that’s new to many of them, learning about evidence and how to weigh it, learning why scientists so often seem to change their minds while in reality zigzagging their way, ever-so-slowly, mostly surely, toward a better approximation of the truth.

*The best thing is, we learned: how do we know what happened? How do we know how old the universe is? How do we know how old Earth is? The Big Bang is like this fantastic theory. I never figured there was so much hard evidence!*

— GE70 student

*They should learn to question everything they hear in their lives.*

— Teaching Fellow Tony Friscia

The basis of current belief is an especially critical component because so much of what the students are introduced to is literally unimaginable. A universe with no center, or rather, every point the center; no matter where you sit, everything rushes away from you. “I can’t imagine it,” a student says. “The big bang happened everywhere at the same time,” explains Morris. “All places were at the same place. If you don’t have difficulty with that, you’re either a genius or you don’t understand what we’re talking about.”

As distant as this seems, it’s all remarkably close to home. The Big Bang was long ago and far away, and yet the lithium that’s used today to treat mental illness was created by its very heat.

Between 10 seconds and three minutes, the basic ingredients of the universe were formed. Meanwhile—as the universe cooled down enough for gravity to get a grip—the quantum mechanical quivering of that primordial soup formed clumps, the essential lumpiness that eventually expanded into clusters of galaxies, which in turn made possible everything from rocks to saber tooth tigers to us.

*The universe has changed drastically, many times over. If we can't get them to appreciate that change is upon us, always has been, always will be, and that change can be catastrophic, then we're all in big trouble. If we can't get them to appreciate (that about) trends in population, trends in environmental degradation, then we're all going to hell in a hand basket.*

— Mark Morris

That lesson is hard to escape. Everything is coming into being, dying out. The seemingly sedate backdrop of quietly twinkling stars turns out, on closer inspection (with x-ray and gamma ray and radio “vision”) to be a stupendously violent place. Stars 100,000 times as luminous as the sun “are burning their candle at both ends,” says Morris. “These stars are not long for this galaxy.”

Everywhere, exploding stars pop off like firecrackers, collapsing into black holes that punch holes in space-time; galaxies collide, tearing each other to pieces “There’s a lot going on out there.”

It’s violent, but it’s also lovely and amazing. “The Milky Way is like a sheet of paper,” says Morris. “It’s really flat.” He shows images of some of the far-flung family of galaxies, several hundred billion strong—a gallery of galaxies. One has great pink cotton-candy spiral arms (the places where stars are forming), bathed in a day-glo green of fluorescing oxygen; it looks like the galaxy is slowly twirling down a cosmic drain, drowning in stars.

### ***Interstellar Alchemy—The Life Cycle of Stars***

By the third week, the cosmos opens a new chapter, experiences another kind of change, as another voice is heard, another discipline introduced.

*Having so many professors is really nice. Everyone has their own specialty, their own style, so it keeps the course interesting.*

— GE70 alum

*If you have a question, you can always get an answer from someone. If one professor doesn’t know, they’ll refer you to someone else. That’s a rare quality for a class.*

— GE70 alum

Up to this point, geophysicist Kevin McKeegan flatly tells the students, “the universe is boring.” Only after the first stars form do we begin to touch the heart of the course, which is about “the evolution of complexity.” It’s time to look into the alchemy that goes in to making elements. As it turns out, nuclear stability is the exception, not the rule. Most collections of protons and neutrons fall apart, later if not sooner. What determines that a certain form of carbon will stick around long enough to string itself into the long chains necessary to create the molecules involved in the machinery of life? At some level, it’s all about  $E=mc^2$ , how energy transforms into matter and vice versa, why reactions go one way and not the other, seeking the lowest energy state, like water rolling downhill.

Another theme emerges: the influence of invisible forces to mold everything from galaxies to atoms. You can’t see the pressure to sink to a lowest energy state any more than you can “see” gravity or natural selection. But the results are palpable. Every element in nature, like every life form, owes its existence to this affinity of energy for minimalization.

Now that the basic ingredients are in hand, the players and the forces, it's possible to see how stars evolve, perhaps even spinning off solar systems like our own in the process, so it's back to astronomy, now for a look at the life cycles of stars.

Marvelous to behold, our star is the exception rather than the rule. Most stars condense out of gas clouds in pairs. Our lone star is an oddity. This is a theme we will hear again and again: How special we are; at the same time, how ordinary.

And another theme still: how systems pull themselves up by their bootstraps in delicately tuned feedback systems. Like an organism, a star is something of a balancing act--held together by its own gravity, pulled toward its center, but at the same time, puffed out by the pressure generated by the nuclear fires inside. Too hot, and it can't hold together; too cold, and it collapses, maybe before it can gobble up enough mass from the surrounding cloud to grow. Like the universe itself, delicately poised between expansion and collapse. On the smallest scales or the largest, in life and in rocks, the cosmos just can't stop looking for equilibrium.

And stars do so much more than just twinkle.

*There were times in cluster when you just said, oooohhhh! A star isn't just a big ball of gas! It's pulling in things to burn and then it spits things back out—everything that we're made of. Is there anything more beautiful than that?*

— GE70 alum

It's amazing how it all fits together—something that's never far from the instructors' minds. The fusion of proton and proton that fuels the cores of stars is the source of all the energy for life, for the petroleum that powers our society, Morris reminds us. "This p-p chain is the source of the sunlight you'll see when you step outside after this lecture. When you feel the warmth of the sunshine on the back of your neck, this is what you're feeling."

The energy packed into atoms when stars explode—slowly leaking out again in radioactive decay—is what powers, among other things, Earth's magnetic field, moving every needle of every compass. It's possible to hear the atoms disintegrate, one by one, as the loud irregular clicks coming from the Geiger counter McKeegan brings to lecture. Snap, crackle, pop goes the uranium in rocks that came raining from space, atoms that got made in an exploding star billions of years ago and are just now falling apart before our eyes. "Listen," he says, as another pops off. "There's a uranium atom made in a star 5 billion years ago, and it just happened to die right here during this lecture."

The rates that atoms fall apart are well known, so it's possible to use radioactive decay to tell when and possibly where the atoms (and even the rock) were created.

And so it goes, back and forth, the terrestrial to the cosmic. That's how you date rock. How do you date the universe? It's not so different. One way is to listen to the radioactive ticking from elements cooked in the earliest stars; how much is left? "What I'm going to tell you today is mathematically based," Morris warns, as he launches into a lecture on nucleocosmochronology. "Don't get flummoxed if I go by an equation too fast. We'll get back to it later. What I want you to carry away is how we date things."

### ***Figuring Out What's Worth Knowing: Questions of Depth and Breadth***

It is, as might be imagined, a constant struggle for the faculty to decide how much to teach, how fast, how much detail to go into, what to leave out, how much scientific jargon to use, how much to simplify.

*Sometimes I feel that we try to tell them too much; we might be better off concentrating on fewer concepts. We realized (last year) that some students don't even understand what gravity is. A lot of students have no clue that the solar system is smaller than the galaxy. This year, we did a much better job on that.*

— Kevin McKeegan

For a great many students, however, struggles are well worth it, and they appreciated the balance of depth and breadth.

*There's not much more you could go into without actually doing the math. It presented the material in a way that's clear for people who aren't science majors, but if you want to delve deeper into certain topics, the accessibility of the professors made that absolutely possible. That's not true of the typical GE class.*

— GE70 alum

*The thing I liked was that it went into enough detail to give you a taste of what's out there and the resources to find out more if you wanted to.*

— GE70 alum

By the time the midterm rolls around, students have remembered nucleocosmochronology as hydroelectrocsmotology, nucleochrondolometry, monocosmochronology. A year after completing the course, few students could remember what nucleocosmochronology meant. But they did remember—and more important, understand—the basic ideas behind how and why atoms disintegrate, and how their slow decay can be used as cosmic clocks. More than anything, they appreciated the chance to participate in a science course to fulfill a GE requirement that wasn't either absurdly narrow, or what they considered to be "dumbed down" for nonscience majors.

*It was a detailed, serious, class, which I think is great. Mostly, what UCLA offers to fulfill life and physical science requirements is ridiculous. If you take three flippant life sciences classes that are super specific, you don't end up with a strong foundation in life science. You end up with some vague memories of some weird off topic, and you really don't learn anything. You've wasted a year.*

— GE70 alum

*Most of those GE classes are not going to get you excited about science. They're either so easy, or you don't learn anything from the work you do.*

— GE70 alum

### ***Who Teaches What: The Cosmos Instructional Team***

Generally, faculty members decide what to teach by playing to their individual strengths and interests, trying as best they can to coordinate with the interests of others. It works, in part, because of the chemistry of this particular group, these particular years. It helps that all instructors are scientists.

*I think it's natural for this to work in a class where it's all science-based. I may not have known the details of stellar nucleosynthesis, but I knew we were all made of stardust*

One of the most difficult aspects of assembling such a team, however, is finding graduate students and post-docs willing to take time away from research to participate. TFs are responsible for labs and have to be able to answer questions on matters far outside their own expertise. Even for professors, the course requires constant learning, re-invention, readjustment. Recyling old lectures from other classes doesn't work. Everything needs to be custom-tailored. The faculty meets every week to coordinate assignments, lectures, field trips, exams, review sessions, grading.

*"This class takes an enormous amount of time. It worked because everyone pulled their weight."*  
— Biologist Blaire Van Valkenburgh

There is an ongoing debate about whether the students are being spoiled by all this help and attention. Never again in their undergraduate careers, some faculty members argued, will they be held by the hand like this. Needless to say, students appreciate the help. Said one GE70 alum, who switched from English to astrophysics after taking the course: "I like the way the cluster was set up for you to succeed as opposed to some of my other classes."

### ***The Restless Earth***

By second half of fall quarter, the solar system is in place, and it's time to look inside the Earth, as best we can, anyhow, peering inside the layers like peeling an onion. Once again, we need new tools, new ways of seeing. You can't "see" through rock, so instead you take soundings, watch the sound shadows cast as Earthquake waves speed through the soft and solid layers of the planet, bending as they go, differently depending on the type of wave, the consistency of the material.

The crust floats on the "ooey, gooey, magma," says McKeegan, and when continental-sized chunks collide, things upstairs can get shook up. Earthquakes in isolation aren't something to fear. It's the combination of earthquakes and people and structures. Co-coordinator Mike Vendrasco demonstrates how continental plates slip and slide and shake using a bucket of rocks, how buildings on top shake, rattle and roll (or not) depending on how they're configured, constructed. A little vibrating platform with miniature buildings brings home his point: "Earthquakes don't kill people; buildings do."

Vendrasco is an evolutionary biologist who is equally at home in geology, equally familiar with the works of Darwin and Jack Handy. McKeegan's interest in geophysics and the formation of elements puts him at home in the stars as well as deep inside the Earth or interrogating rocks from space. Teaching fellow Tony Friscia from Life Sciences not only understands rocks, but climbs them, leading UCLA outdoor adventures. Morris knows his faults. (This cluster is blessed with rock stars, as we shall see.) Van Valkenburgh, to everyone's surprise, ventures to crack a physics joke at a meeting.

### ***Living Laboratories***

The cluster is in all respects a team, a point made abundantly clear on the first of several field trips. As the bus reluctantly winds its way up the steep road to Mt. Wilson, Friscia scrambles up some rocks to point out geological fault lines. McKeegan, who lectured on the formation of planetary atmospheres, tells the students to stop and "take a deep breath. It's the only place in the solar system where you can do that." Even our precious atmosphere, the students learn, coats the planet with a very thin skin—no thicker, relatively, than the shellac covering a classroom globe.

At the Mt Wilson solar telescope, an astronomer guide shows them dark smudges on the surface of the sun--sunspots bigger than Earth where the internal magnetic fields of the star have gotten

tangled up, occasionally breaking off to spew showers of electrically charged particles toward Earth.

Morris takes the students to the spot where the speed of light was first accurately measured, and to the telescope where the recession of galaxies was first glimpsed by Hubble—where humanity first learned that the Milky Way was not alone but only one among a host of “island universes.”

Astronomy isn’t for wimps, students also learn, as they contemplate the rickety chair where Mr. Hubble sat freezing night after freezing night to gather the dribblings of distant star light. It takes courage, or at least the stamina to stomach long periods of discomfort. It feels like an adventure. For students, it can also feel like a family; this is something they most emphatically did not expect when they came to UCLA.

*People would say: ‘Oh, you’re going to UCLA. Your classes are going to be huge. You’ll never meet your professors.’ And I’d say: ‘I don’t know what you’re talking about’.*

— GE70 alum

*The best thing was having the close, personal contact with professors for more than a quarter. You’re all freshmen—scared and anxious and excited. And you get to go through it together. It’s so much more than just another UCLA course.*

— GE70 alum

Field trips serve multiple purposes. On the simplest level, they make the course a friendly experience—a nontrivial result.

*All the social aspects—the barbeques, the field trips, it made you feel completely free to ask questions. It made you think about the material outside of class. That doesn’t happen when you don’t get to know a professor.*

— GE70 alum

They also bring home the fact that GE70 at heart a laboratory course. It’s one thing to watch Vendrasco drag buckets of rocks across the lecture hall to mimic the sliding of continental plates, set off Earthquakes in miniature buildings. It’s quite another, however, to straddle the San Andreas fault—one foot heading toward Mexico while the other makes tracks for San Francisco. Or to see how sedimentary layers laid down in water eons ago got tangled up in knots as the Earth moved, the tortured rocks swirled into almost circular patterns, folded over and over like egg whites.

It’s just the stuff for climbing on, as both students and instructors do at the Devil’s Punchbowl, a place where one can’t help but feel that solid rock, in slow mo, behaves a lot like Silly Putty. It is the day the Earth moved for many of these kids. As one alum described a previous year’s fossil-hunting field trip:

*You go out into the desert and you run around and play in the dirt with professors who know everything there is to know about it. That was really a religious experience. We were picking up these fossils—holding these things in your hand—and you got the feeling you could hear the ocean. This used to be under water! The dawn of time existed for me while I was there. It was like time was abolished, and I was living back in that moment.*

There is present life here, today, too. Snakes, red-tailed hawks, horned owls, all kinds of flora no one can identify. Finding out what professors *don’t* know is also, it turns out, an important part of these experiences. Because all instructors come to (almost) all lectures, and attend (almost) all field

trips, there's lots of time to share ignorance as well as knowledge—something that helps even the experts to clarify their points and especially helps the students.

*It felt good to know we weren't the only ones who were struggling.*

— GE70 alum

### ***Making the Connections***

On the way back to campus, there are Beatles songs and bad food, a movie about giant burrowing carnivorous worms. But mostly, there's a sense that things connect in a way that they often don't during the rest of the students' UCLA education." I like the way it all hangs together, that it's not separate categories," said one student on the bus, a future filmmaker.

Cluster alums had a much broader basis for comparison:

*The university system makes it difficult to study anything from more than one point of view, and I thought the cluster did an amazing job of that. It's difficult to find synthesis in your classes. Poli sci classes and history classes and philosophy classes are all narrowly focused; they all have a particular methodology. I can take classes that are all talking about the same thing, but you might never know it. They don't read each other's literature; they don't find a common ground.*

— GE70 alum

*I wish more professors would try to coordinate like that, so that each course isn't its own, separate core of knowledge, unrelated to the rest, where students have to make their own connections.*

— GE70 alum

*The very deep and narrow science courses tend to give you all these formulas. We are North Campus majors, and we are going to forget all the formulas. This course is a comprehensive view of science, and I carry this with me instead of just some formulas. And as a result, I remember quite a few of the details.*

— GE70 alum

Perhaps surprisingly, science majors, too, felt grateful for the cohesiveness of science as presented in the course.

*As a science major, it's great. You don't have to wait four quarters to get into things. You don't have to take all the math, all the prerequisites. You don't have to take biology and geology and physics. You get everything. It puts it all together with areas of science I wouldn't otherwise get into.*

— GE70 alum

Even the most hard core North Campus types can't help but see connections as the quarter comes to a close. Science meets politics head on in the issue of global warming, where it's impossible to separate the planet from the people who've come to inhabit it. The Earth's atmospheric blanket absorbs light mostly in visible wavelengths—the ones we see (not a coincidence, of course, but a direct result of evolutionary pressures). That energy, however, is re-radiated from the Earth mainly in the infrared, so that a lot gets absorbed by water vapor and CO<sub>2</sub>. In effect, the atmosphere behaves like the glass of a greenhouse. This was essential to keep the planet warm when the sun was dim and cool. Now, however, humans are pumping so much heat-absorbing gas into the air that catastrophic consequences may occur—in fact, are probably already occurring.

We not only have an atmosphere; we change it. Some of us drastically. The U.S. is responsible for more than 25 per cent of greenhouse gases released into the atmosphere annually.

As for the would-be arts, philosophy, literature majors, they're invited to ponder perhaps the deepest question of all—certainly not for the first time in their lives, but for the first time in a scientific context. What is our role in the cosmos?

On the one hand, it's clear that the main lesson of the past quarter has been humility. The Earth is not the Center of anything. The Sun is an ordinary star in an ordinary galaxy. We're not even the main constituent of the universe; the matter we're made of comprises but a tiny percentage of all the matter and energy in the universe. The rest is "dark," unknown.

"We're not special," Morris tells the students, adding: "I'm not telling you this to humiliate you."

On the other hand, we seem to be very special indeed. If quarks were just a little lighter or gravity just a little stronger; if the expansion of the universe were just a little faster (or slower); if the universe contained just a smidge more (or a smidge less) matter, we wouldn't be around to ask these questions. Can this be a coincidence? Perhaps. But it also might be explained by what's known as the Anthropic Principle. In short, in any other universe, life (never mind humans) wouldn't have evolved. Therefore, the universe we inhabit is the only universe we could *possibly* inhabit. That doesn't preclude other universes with different kinds of particles, forces, fundamental laws; it simply means that we don't (and can't) live in them.

*The anthropic principle was especially interesting to me because of the way it connects to philosophy and math. I was glad to have the scientific perspective to compare with the philosophical and literary perspective. It definitely blurred the lines between philosophy and science.*

— GE70 alum

"Only connect," E.M. Forster wrote. Students got this lesson well. A dance major found that she started thinking differently about movement, forces, space and time: "Now I think, Oh, I know *why* my body does this..."

*It was amazing how everything started to connect. The way of thinking about things I learned in cluster has made it possible for every single one of my classes to have something to do with each other. They're all interrelated. (For example), literature is about human behavior, and human behavior can be explained by an evolutionary perspective.*

— GE70 alum

### ***Evolution: The Thread that Runs so True***

So even though Winter Quarter switches emphasis to the life sciences, the transition is not at all abrupt, because the thread of evolution is never lost; it's only another chapter in the story that's been unfolding since the Big Bang—of how everything came to be and evolved ultimately to the very existence of the students in the classroom.

*We don't try to do everything. Everything we do is restricted to this thread of evolution.* — Mark Morris

It's every bit as difficult, it turns out, to look back at our biological origins as it is to look back at the first moments of the universe; as hard to know what life was up to 4 billion years ago as it is to know what the universe was doing at the dawn of time. So biologists, like physicists, need to

develop precisely tailored tools. One of the earliest tools developed was simple classification of like characteristics—a process Vendrasco illustrates with beer bottles of various colors, shapes, ornamentation. Groupings allow scientists to form hypotheses as to why certain characteristics are shared, others not. Why and how are penguins and vultures and turkeys the same? In what ways are they different?

This same idea takes a more sophisticated form in the development of the cladogram—a graphic depiction of relationships and how they may have developed over time, where lineages may have diverged. Where Vendrasco used beer bottles, Friscia in his lecture groups Pokeman creatures, but the point is the same. Grouping is a way to tease out otherwise invisible (or at least obscured) relationships—as is the use of molecular clocks based on the way changes in DNA mount up over time.

In effect, these tools are not so different from telescopes or microscopes or particle accelerators that allow us to see far beyond our immediate senses, travel to realms remote from human experience. Indeed, on one level, GE70 can be enjoyed primarily as a travelogue—the trip of a lifetime—that takes students to the most exotic corners of space and time. The first quarter transported them to the Big Bang, the insides of stars, the center of the Earth, the edge of the universe and the earliest days of the solar system. The sights of the second quarter are no less exotic, the concepts and players no less strange.

Here we are with Darwin on the Beagle, constantly seasick and confused by the island-to-island variations in creatures he saw in the Galapagos: Giant lumbering tortoises with variously-shaped necks and shells (Darwin liked to jump on their backs to hitch a ride); finches with a broad range of different beaks; iguanas that swam in the sea, gobbled down seaweed, then sat on hot rocks until the stuff cooked inside their stomachs. Talk about weird science!

Not only is the cast of characters new; so are the forces at work. Instead of gravity and nuclear energy, living things (in addition) are sculpted by random genetic mutation and natural selection. These are the forces behind everything from the interior decorating skills of the bower bird to the nasty bite of the Komodo and group gropes of “she-male” garter snakes. Just as the slowly leaking nuclear energy in rocks sends the continental plates drifting and volcanoes erupting, so evolutionary pressure can alter the shape of a beak, the length of a neck, the size of the brain—make peacock features pretty and skunks smelly. It even sculpts unrelated animals into similar forms. Anteaters of all stripes and species develop long snouts, sticky tongues, similar guts simply because all have evolved (separately) to feed on the same meal.

There were even explosions, almost as dramatic as the Big Bang. Nearly 550 million years ago, life on Earth suddenly and inexplicably burst forth with an outpouring of new species the likes of which had never been seen before or since. One creature had five eyes; another looked so weird with its straight spiky legs (they turned out to be spines) that it was named Hallucigenia. What a strange trip it’s been!

*It's like the Magic School Bus.*

—GE70 alum

Conclusions that can be reached from studying the fossils of these creatures and the rock formations in which they’re found are bizarre as well. The geological time scales required for evolution took a lot of getting used to, even for Darwin. How do you think about changes that occurred over millions of years when our lifetimes span not even 100? There are stranger conclusions still: Similarities among organisms can be explained because *all living things are*

*descended from a common ancestor!* This is no less hard for students to get their minds around than a universe with no center, or a time before time began. Some—to the profound disappointment of faculty members—never do buy into evolution as fact rather than theory.

*I have a strong religious background. I didn't believe in evolution and I still don't. But I respect the scientists' beliefs now. I can't just say, no, you're wrong. You can't deny that change is going on. The (continental) plates are moving beneath us. It's a lot easier in high school just to dismiss these things. I came away from the course with the urge to explore why I believe what I believe. I'm grateful for that. If I hadn't been smacked in the face, I would haven't have felt the need to search further. I could have stayed complacent.*

— GE70 alum

All the pieces begin to come together as it becomes clear that even geography—dumb rocks propelled by the energy of radioactive decay moving around continental plates—has a huge effect on the evolution of species. As mountains rise, islands become isolated from the mainland, currents form barriers in seas, species can no longer interbreed, giving rise to separate lineages. (And let us not forget that the energy of radioactive decay was created during supernova explosions.)

The circling themes give rise to a crescendo of increasing complexity as species bud or branch or go extinct with a proliferation of feathers and fur, scales and claws. “Evolution is a blur,” Van Valkenburgh emphasizes. The creation of a new species is not clear-cut. In extreme instances, separate species will even interbreed. Evolution proceeds in fits and starts. There is a sense of racing through the history of the universe and life at full throttle; it’s almost too much.

“As the fossil record gets better, things get more confusing,” says Van Valkenburgh. “The more you fill in the gaps, the more lines tend to blur. It’s exactly what you would expect if you could see evolution in action.”

Scientists sift through shards of bone like particle tracks, looking for pieces of the puzzle, trying to arrange them into a coherent picture.

### ***From Science Anxiety to Science as Adventure***

If not everyone in the class is convinced of the reality of evolution—or switches majors from humanities to science—the course nonetheless has an enormous effect on the way students think about science per se. For the first time, many of these soon-to-be writers and dancers and lawyers and politicians begin to regard science as an appealing adventure—not simply a requirement to get out of the way with as little pain as possible. Further, they regard it as an adventure in which they themselves can actually partake. This, for many, is a revelation.

*I was nervous about physics, but it was presented in a way that you didn't have to be scared of it. (A big surprise was that physics) is enjoyment reading! You'd never think that about physics! It's amazing! That's very valuable. Who would have thought that physics could be that interesting? It makes you think that anything that's out there could be interesting.*

— GE70 alum

*It was like jumping into this pool and finding you can breathe under water.*

— GE70 alum

*I can approach science now, instead of saying: ‘oh, that's not who I am. I'll leave that to the (nerds). Normally, I'm focused on political news, current events. But now, I read (science related*

*articles) all the time. Something about environmental policy might relate to something Mike had to say about destruction of species.*

— GE70 alum

This is science in the making. Most of what is presented in these lectures (like those in fall quarter) wasn't even known 20 years ago. Much is only a few years old. When Morris lectures on the possibility of life beyond Earth, it's clear that this science will only take off during the lifetime of students. For the present, exobiology is a "science with no data," he tells them. "But in our lifetime, there's a good possibility that we'll have data." Just a few years ago, no planets were known orbiting stars beyond earth. Now, says Morris, "every astronomy meeting, there's a new planet. There's been a revolution."

*I was talking to one student who was reading Kant. I don't think the appreciation of Kant has changed appreciably in the past decades. But we're talking about fundamental facts of nature that just weren't known when we were in school.*

— Kevin McKeegan

*I had the feeling that these current discoveries aren't so far fetched as I had originally thought them to be. I had thought, oh, 'it's so south campus, it's so out there, I can't even think about things like that.' Then we got our hands dirty and actually tried to (understand) this stuff. And even though we couldn't understand it all, it's not so way out there that I can't even contemplate it.*

— GE70 alum

### ***Creating Communities of Learning***

This carefully orchestrated interplay of life and the cosmos, lecture and first-hand experience, is, as previously stated, enormously time consuming for faculty, and difficult for departments to justify.

*There's a general consensus that it's not worth it. Because it doesn't generate a lot of geology majors. It takes people away. We don't have enough people to teach core curriculum as is. And the department doesn't get proper credit. The faculty doesn't get proper credit.*

— Kevin McKeegan

That said, students both appeared to both understand and appreciate that the commitment.

*I felt as much work as I put into it, I got back from the faculty, which is pretty unusual at UCLA. The professors made themselves exceptionally available.*

— GE70 alum

One alum particularly enjoys recounting the night she and some fellow students stayed up late working on a lab assignment, and got stuck on one of the questions.

*This was about midnight. So I said, guys, we are not getting anywhere on this, let's go see if we can post a question on the discussion board, and all I got is a blank screen and I thought maybe the web site was broken. But I tried posting anyway. And I said, if anyone is reading this at midnight, here's my question, if anyone knows what they're talking about, please call us. About an hour later, we get a call. It's this guy. And he says, I think I can probably answer your question for you, and I wondered if you still needed help. And we said, oh yeah! What was your name again? I thought it was some little nerdy guy up in the dorms with nothing to do at 1 in the morning but surf the class web site and answer my stupid question. And he said, this is your professor, Mark Morris. Calls us at one in the morning to help us with our homework! And it absolutely, literally, transformed my perception of education. He stayed on the phone with us for 20 minutes, helping us*

*to do this lab. You can't match that experience. And we tried it again. And this time Mike Vendrasco called us. It was amazing.*

For professors, too, the work had unexpected rewards. McKeegan, for example, found that it affected his own research. After Morris' lecture on the influence of the moon on Earth, and stupendous tides that washed over the planet during earlier epochs, he found himself bringing the idea up in a graduate seminar he was teaching.

*I thought it was cool that a freshman class was influencing a graduate seminar in a sub discipline. One of the more interesting aspects of participating in this cluster as an instructor is that you're also a student, and I've learned a tremendous amount about fields that I wouldn't necessarily go into. Even if it doesn't result in publication, it stimulates your brain.*

— Kevin McKeegan

### **Cosmos Nation**

Everything changes—including the story of the cosmos itself.

The last few lectures make it clear that change—at least on our little corner of the cosmos—is getting out of control. Human actions are undoing much of the work of evolution in a remarkably short period of time. We wiped out the moa and the mammoth, the do-do and the pygmy hippo, the ground sloth and the passenger pigeon. By the end of this century, we may well have extinguished half the species of plants and animals that ever lived. It's chilling how easy it is to snuff out life. Here today, gone tomorrow. Much of it caused by us. George is lonesome because of whole scale slaughter of giant tortoises by humans. Pandas are almost extinct. The Earth is becoming a lot less rich, and we are squeezing the life out of the planet.

The problem is compounded by the rapidly accelerating pace of change. Adaptation to changing environments takes long periods of time. Relatively speaking, clear cutting of forests, pollution, destruction of ecosystems, happens over night.

Vendrasco shows images reminiscent of the gruesome footage from driver education classes used to instill caution in new drivers. Butchered manatees caught in power boat propellers; bloody remains of slaughtered whales and sharks and elephants and rhinos, killed sometimes for food but more often for dubious purposes having to do with belief in magical powers of horns or fins or testicles. He brings in a steel trap of the kind people use to exterminate “pest” species like coyotes, brings a stick close to it. Suddenly, snap! The stick’s chopped in two. “Maybe it’s the leg of something that stepped into the trap by mistake,” says Vendrasco. “Maybe a California condor. Oops! Oh, you were the last female? Your species is going extinct? Too bad!”

We are destroying what sustains us—the living planet that provides our air, our food, the medicine to cure ills; even organisms that clean our water. One break in the tightly-linked chain of life can destroy whole webs of interdependent species.

Students will have a chance to explore each of these subjects more deeply—as well as others—during the Spring Seminars, each a special topic developed by the instructor to reflect his or her interests. This spring, the subjects range from time and energy to history of science, planet-finding, and endangered ecosystems.

*It's sold as a treat for them, but it's a treat for us. We're all tired by the third quarter. So it's a treat to read what we want to read. You get to take them to cool places.*

— Tony Friscia

The last class is highly emotional, personal, passionate—a reprise of the first lecture only with heart and soul and music. Friscia—a vegetarian—quantifies the high energy costs of eating meat (10 times as much energy goes into making a burger than a soy shake of nutritional equivalence.) McKeegan rants against wasteful SUVs, and other ways we’re throwing away the limited energy reserves of the planet (while polluting it all the more). “Driving an SUV for one year (instead of an average car) is like leaving your refrigerator door open for six years.” Van Valkenburgh gives a troubling perspective on our lowering baseline of expectations. We get accustomed to dirty water, polluted air, disappearing species, scarring of the landscape, and it all happens so incrementally, that we don’t notice. Morris talks about a Big Bang that is taking place before our eyes in population, a literal explosion that adds the population of San Francisco to our planet every three days. Every 20 minutes, the world adds another 2800 human lives, but loses one or more entire species of animal or plant life—at least 27,000 species per year. “For every two people standing in line in front of you now, there will be three in 2050.”

Vendrasco decides that the cluster should end as it began, with a bang, so he puts on a sound and light show, belting out “The Sun is a Mass of Incandescent Gas” (from the song “Why the Sun Shines”), accompanying himself on accordion, with Morris on electric guitar, a former UCLA paleontology grad student on drums.

There is a prolonged standing ovation. Later in the day, an anonymous e mail comes to the faculty, reproduced here verbatim.

*Today's lecture was so beautiful. It validated my belief that you are all wonderful people that have surpassed the call of duty to us--the future. Values and Passions came out today from each instructor and they were so moving to me. Each of you offered a perspective into your lives that is so rare to encounter outside intimate relationships. Whether it was a lesson of life, key issues of the present and future, deep questions to consider or just some awesome entertaining fun, it was all very thoughtful and eye-opening.*

*I want to say to you all, you have made a difference and that I'll carry a piece of your souls throughout my life. I won't ever look at a Big Mac the same way. I won't buy a SUV. I will always picture Mike with an accordion. I'll definitely consider adoption. I won't forget there is Beauty everywhere, even in science. I will question my path often and I will follow my heart.*

*Thank you. I can't say enough. I will truly miss coming to this class.*

*some student in your cosmos class,  
some being in the universe”*