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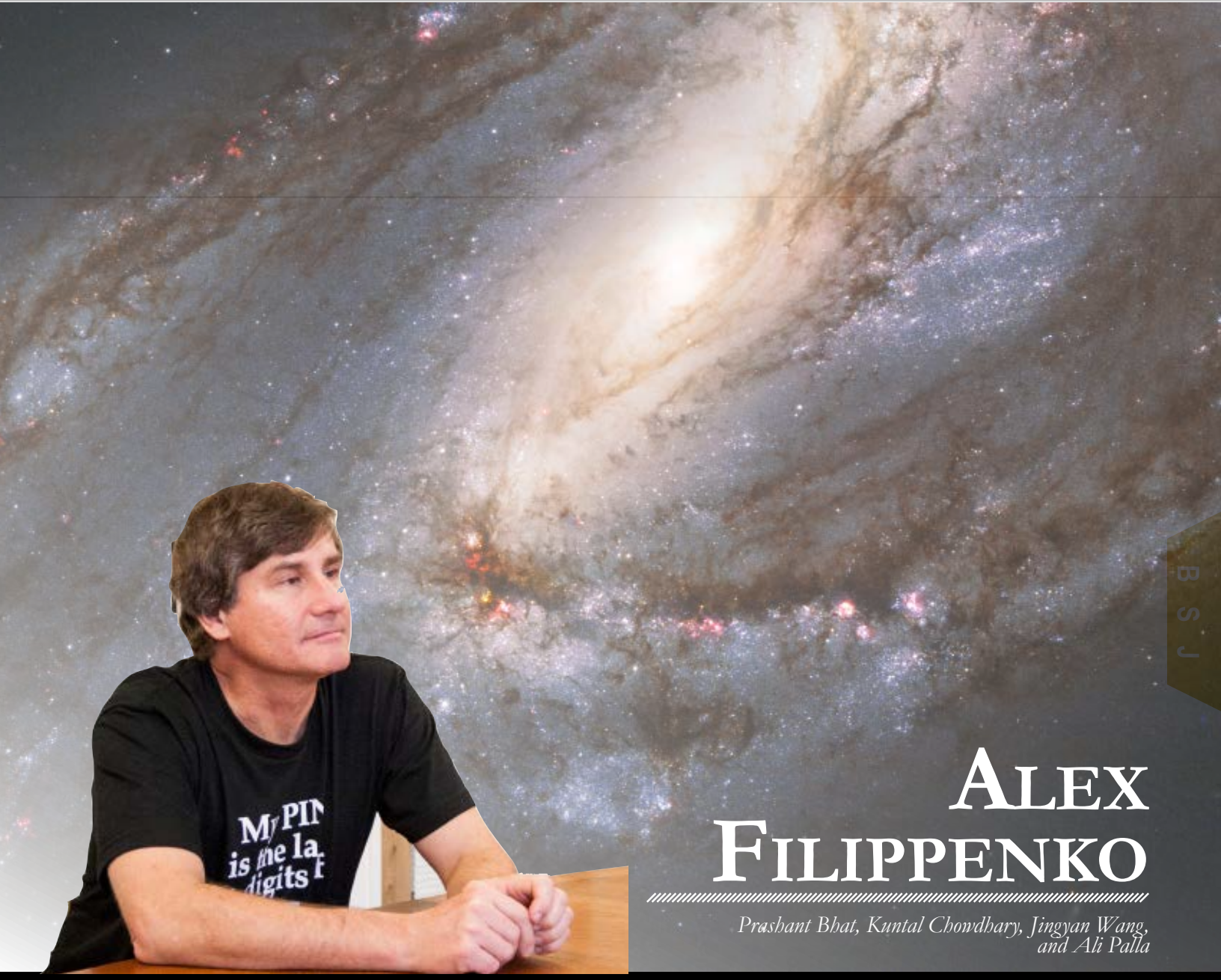
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Undergraduate



ALEX FILIPPENKO

*Prashant Bhat, Kuntal Chowdhary, Jingyan Wang,
and Ali Palla*

BSJ had the exciting opportunity to interview UC Berkeley's 9 time "Best Professor" winner, Professor Alexei Filippenko, an astrophysicist and a professor of astronomy. His highly acclaimed research on progenitor stars and explosion mechanisms of different types of supernovae has appeared in numerous TV shows, documentaries, and textbooks. Stemming from our topic on Death and Dying, we discussed the exciting phenomena of star death and the formation of brilliant supernovae.

BSJ: To begin, we wanted to know how you got involved in cosmos research and what led you to focus on supernovae?

F: As a graduate student at Caltech, I was doing a survey of the five hundred brightest, nearest galaxies in the northern hemisphere to find evidence for a giant black hole that's swallowing material. Little miniature quasars. Quasars are bright, luminous bodies very far away. We think that they are big black holes swallowing lots of material at the center of galaxies. So in nearby parts of the universe there should be descendents of quasars. In other words, the black holes should still be

there, swallowing material at a lower rate.

I was doing a survey at the 200-inch (5.1 meter) Hale Telescope at the Palomar Observatory with my former thesis advisor at Caltech, Wal Sargent. This is now February of 1985, I'm a post-doctoral scholar now at Berkeley and at the end of the fifth night of the five night observing run I had time left for just two more galaxies to observe. I had a hundred possibilities because the survey was still in its early stages—I chose a galaxy almost at random because the picture of it looked interesting. So I said, "let's survey that one."

When we pointed the telescope to that galaxy, we

noticed a bright star that seemed not to be in the right place. In other words, it wasn't the bright central part of the galaxy. So I said, well look as long as we getting a spectrum of the nucleus of the galaxy, let's get a spectrum of this other thing that's near the nucleus in case it's something interesting. We got a spectrum and it turned out to be an exploding star. So I kind of found one almost by accident without looking for it specifically. And it turned out to be a particularly interesting type: a new kind of stellar explosion, which I studied in the course of the next few weeks and we published a paper on it—I became really interested in stellar explosions as a result of that chance discovery. A message I can give is to be on the lookout for opportunities and take full advantage of them.

BSJ: How do you determine accurate measurements of supernovae and other stellar particles from millions of light years away?

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That's like the neutron star rebounding off of itself because the core collapses, overshoots like on a trampoline and then you rebound. So that's that.”

F: Well, we might be millions or even billions of light years away, but with a big telescope we can collect quite a bit of light—that's what a telescope does. A gigantic eyeball that's gathering light. We can pass that light through a prism or reflect it off of a grating and produce a spectrum. And with the spectrum we can study the chemical composition, the speed of the ejecta, the density of gases, etc. It is really through spectroscopy that we learn about the physics of the object and also through repeatedly taking pictures of the supernova and recording how fast it brightens and

BSJ: What are the different types of supernovae and how do you distinguish them?

F: The major classification is based on whether the spectrum shows obvious hydrogen or not. If it shows

hydrogen it's called Type II and if it doesn't show hydrogen it's called Type I. Now it turns out that Type I supernovae have several different subtypes: Ia, Ib, Ic. Ia are the classical Type I supernovae that are thought to be the thermonuclear runaway of a white dwarf star at the end of its life when it gets enough material from a companion star. The Ib and Ic supernovae are thought to be more related to Type II supernovae. The Type IIs are massive stars whose iron core collapses at the end of its life. That launches a rebound, which is then the explosion of the outer most parts. Core collapse versus thermonuclear runaway.

The Ib and Ic supernovae I found in 1985 [mentioned earlier] helped solidify this idea that some Type Is are not the thermonuclear runaway of a white dwarf, but rather are the core collapse of a massive star that lost the outer envelope of hydrogen prior to an explosion. It spectroscopically looks like a Type I because it doesn't

have hydrogen, but a bit of a weird Type I because it's not a white dwarf. There are various observable characteristics from which we then try to get a physical understanding of what's going on. And in the physical understanding there's the thermonuclear runaway of a white dwarf versus the collapse of the iron core of a massive star. Those are the two main mechanisms.

BSJ: It's amazing how the most primitive element like hydrogen that we rely on most is absent from Type I supernovae.

F: Right. Massive stars have gotten rid of their hydrogen prior to the explosion. They can do that through winds of their own and also by transferring material to a companion star. They can get rid of the hydrogen that way as well.

BSJ: So how do you know which stars to research and

what parameters do you look at?

F: What we do is take photographs of thousands of galaxies each week and then we repeat the process and even at the rate of one supernova or two supernovae per century per galaxy. If you're looking at enough galaxies some of those will produce a supernova. And once we find the supernova we study it in detail. We start taking more detailed measurements of it. We'd love to be able to predict which star will become a supernova and we can predict it sort of in a general way like beetlejuice: the left shoulder of our eye. And I can say with a lot of confidence that it will blow up sometime in the next half a million years. But I don't know when. It could be tonight, it could be half a million years from now. We would love to be able to predict that. We can't yet.

BSJ: Going back to the theme of death and core collapse, there are many descriptions and definitions

of how massive stars can undergo core collapse. How do you describe star death/collapse to your students?

F: Near the end of a star's life, there's been a sequence of nuclear reactions where the ashes of one set of nuclear reactions becomes the fuel for the next set. So our sun right now is fusing hydrogen to helium and it does that for ten billion years, but later on it will fuse helium to carbon and oxygen. And our own sun will stop at that point because it's not massive enough. But much more massive stars (say eight or ten times the mass of the sun or above) can fuse carbon and oxygen into things like neon and magnesium. And then silicon and sulfur and then finally iron. And there might be a few steps in between there. But the point is you build up an iron core. At each stage, the star releases energy through this nuclear fusion. Now iron nuclei fusing together would require energy rather than liberate energy. Iron is the most tightly bound of the atomic nuclei; fusing iron together wouldn't do the star any good.

It wouldn't keep the star hot inside and pressurized. What happens is the iron core builds up and then reaches a sufficiently big mass that it can no longer hold itself up against gravity, so it collapses. And the protons and electrons combine to form neutrons and neutrinos and you get a ball of neutrons, a neutron star, which overshoots its equilibrium point.. becomes smaller than it normally would, and then it rebounds a little bit. And the rebound that hits the surrounding layers launches them outward. And then the neutrinos that are also produced also help push on this material and that creates a successful explosion. So that in a simple way is kind of, you know, what happens.

Imagine the basketball rebounding off the floor. That's like the neutron star rebounding off of itself because the core collapses, overshoots like on a trampoline and then you rebound. So that's that. And then if you have material around it, whose pressure support has suddenly vanished, it will fall, for example, a bouncing

tennis ball. Now these balls normally don't go up to the height where they started because some energy has dissipated due to the collision. But, if I put them one top of each other, the tennis ball goes shooting off. There is this rebound which in the sense chemically launches the explosion. And just as in the case of Earth's gravity, the ball, if it could go high enough, wouldn't come down. So, two, this mechanism fails to explode the star completely. That's where you need these neutrinos, which are not very interactive, but some of them do interact and help push the material out. That, in some cases, gives you a successful explosion. That's the basic idea of core collapse of a supernova. What's left over is a neutron star, in some cases a black hole because the neutron star is sometimes too massive and it continues to collapse to form a black hole. But the rest of the material is ejected away.

BSJ: So as you were saying, once a star collapses, it becomes either a supernovae or a black hole. What are

“... a team of mostly undergraduate students looked at the few dozen images that the software tagged on the previous night as being potentially interesting, and with their superior eye-brain combination (laughs), would decide which ones would be genuinely supernovae and worthy of follow-up observations.”

the factors that ultimately determine a star's fate? In your papers, we had seen several references to the Chandrasekar limit, so we were hoping you could expand on that.

F: In the case of a core collapse of supernovae, normally you would get a neutron star. But if the collapsing core is too massive, then either the whole star can collapse to form a black hole, or you get a rebound if it stops temporarily as neutron star. You get this rebound, you get bunch of neutrinos and you can get a successful explosion, but the neutron star will continue to collapse to form a black hole. With massive you can go directly to a black hole, or through the supernovae explosion, ending up as black hole. Most of the time, it ends up as a neutron star.

Now the Chandrasekar limit is technically the limit beyond which a white dwarf cannot grow. A white dwarf is what the Sun will become in about 7 billion years. And if it were to gain material from a companion, it could not exceed 1.4 Solar Masses and it would explode or collapse. In the case of an iron core of a massive star, it's the iron core counterpart to the Chandrasekar limit. The limiting mass beyond so called electron degeneracy pressure, which is what holds these things up. Basically, electrons don't want to be in the same state because they are fermions. They have the Pauli Exclusion Principles. They don't want to be in the same state, yet they are being crammed into a smaller and smaller volume. So to be in that state, some electrons have to have a tremendously high momentum and tremendously high energy. This is not thermal random energy, it is an energy based on the Pauli Exclusion Principle and on the Heisenberg Uncertainty Principle. You have this quantum mechanical pressure holding the thing up and beyond 1.4 solarmasses, the Chandrasekar limit, and the degeneracy pressure is insufficient to hold something up against the pull of gravity.

BSJ: So taking a step back, you are in charge of the Katzman's Automatic Imaging Telescope (KAIT) down in San Jose. Can you tell us a bit about the project and how you became involved?

F: In 1989, I got an award from the National Science Foundation called the Presidential Young Investigator Award. It gave me money with which to research, and they would give me more money matching what money I would get from private donors, industries, and etc. I got a telescope company

to donate a fraction of a telescope, which was worth some money, and then I got money from the NSF and bought an equivalent amount of equipment from the same company, so I effectively got everything at half cost. KAIT takes CCD images (digital images) of galaxies. Typically a thousand per night, maybe several thousand (7000-10000) a week and it repeats the process. I had a research associate, Wei Dong Lee, who unfortunately passed away in December of 2011, program this whole thing to take images of galaxies and automatically compare the new images with the old images of the same galaxies. Out of the 1000 images a night, we would get 15 candidate supernovae, but not all of them were for sure supernovae because sometimes cosmic rays, and charged particles interact with the detector and they look like a star or an asteroid may be passing through the field of view and it would look like a star. Then, a team of mostly undergraduate students looked at the few dozen images that the software tagged on the previous night as being potentially interesting, and with their superior eye-brain combination (laughs), would decide which ones would be genuinely supernovae and worthy of follow-up observations.

For about a decade, we led the world in terms of total number of new exploding stars— relatively nearby ones (within a few hundred million light years) discovered each year. We would typically find 80-90 each year and we would study some of them in detail. Now there are bigger telescopes with wider-angle cameras that are able to scan a bigger fraction of the sky. More galaxies in a shorter time. But for 10 years, we were the undisputed leaders in finding them. Now we are evolving in the sense that, since other groups are finding more supernovae now, we have turned our attention to finding younger ones. We look at fewer galaxies, but we look at them more frequently. For example, each night, we will look at the same galaxies, instead of once a week. So if we discover a supernova, we are likely to discover it at an earlier stage of its explosions when a lot of the interesting physics is being revealed. We are also spending more of our time following up on supernovae that we or other people discovered. It is no longer the world's most prolific discovery machine, but it is still at the leading edge of research.

BSJ: How long did it take the newer, wider-angle telescopes to surpass KAIT?

F: For 10 years we were told, we will blow you out of the water pretty soon, and I kept waiting. But more power to them, the science goes forward faster, that's great. But in fact it took other groups 10 years to achieve what we achieved. So we had a pretty good run, and we're still relevant, we're still doing good stuff. If I were to start a new project, I wouldn't build the exact same thing I built 15 years ago.

BSJ: What is the, are the broader implications of your supernovae research, how does it help us understand the universe?

F: That's a good question— the supernovae people might say why spend any money on this kind of research? But there are a number of issues: first, we are learning our origins better; we see the elements of which we consist being created by stars and by the explosions themselves, and ejected into space, okay. Over many generations of stellar birth and death you get this gradual enrichment of the primarily hydrogen and helium gases with which the universe was born and you get an enrichment of heavier elements.

And then eventually clouds of gas can form that are sufficiently enriched in heavy elements that once they collapse to form stars and planetary systems, some of those planets will be rocky earth like planets, and this clearly happened in our own solar system, and so we arose as a result of all these previous generations of stellar birth and death through explosions. So in a sense, Carl Sagan used to say that we are made of "star stuff" or star dust; quite literally, the carbon in your cells, the oxygen that you breathe, the calcium in your bones, the iron in your red blood cells were formed through nuclear reactions in stars. The realization that we came from stars is just one of the most amazing discoveries in the history of science.

So we do it because we want to know, and in science of course there always is or there often are unanticipated spin-offs of a more practical nature. At the very least, we get kids excited about science and they go into technical fields. But, the hook was this cool stuff that kids hear about in the news, and they then study math and science and technology and most of them go on into more practical fields like applied physics, or engineering, or computer science, and that's a direct benefit to society.

The long-term benefits from science are harder to

quantify or predict, but it was Newton sitting around trying to understand why the moon is in orbit, that led to the development of much of classical physics. He didn't do it to build a better toaster. It was Einstein sitting around trying to understand the motion of objects at high speeds, or the nature of gravity itself, that led to special and general relativity, which are now used in technology. GPS wouldn't work if we didn't take into account the equations of special and general relativity. Quantum physicists a century ago like Max Plank and Einstein, Schrödinger and Bohr, and many others again didn't have any practical applications whatsoever in mind at the time. They were just trying to understand the nature of the atom and radiation at a deeper level. And now it's very difficult to conceive of the high-tech world, based on computers and microchips, and lasers and so forth. It is hard to conceive of our modern world without understanding microscopic details, in particular, quantum physics.

That was a century ago and if you had ever told those physicists that in 2013 the world would be the way it is based on quantum physics, they would have said "Let's lock you up in the funny farm, you're insane." So it's difficult to predict what the long-term benefits will be of this kind of research.



"We are learning our origins better; we see the elements of which we consist being created by stars and by the explosions themselves, and ejected into space."

"Scientists and philosophers can co-exist and can have fruitful conversations with one another."

Another aspect of the supernovae and why they're important and interesting is that they're very powerful; they're very luminous and we can see them at very large distances. If we know how luminous, how powerful they really are by calibrating nearby ones like the ones we find with KAIT, you can determine the distance of that supernova and hence the distance of the galaxy in which it's located. And by studying these supernovae in galaxies at progressively bigger distances, we're studying them progressively farther back into the past. We can therefore examine the history of the universe, and in particular, we can study the expansion history.

Supernovae themselves have a lot – they're interesting in of in themselves, but they also tell us about the birth and evolution of the elements and the evolution of our universe as a whole.

BSJ: Amongst all the achievements you've had over your years as a researcher, what do you consider to be your proudest achievement?

F: Well I'm enormously proud of my contributions to the research that led to the Nobel Prize. My main job on both teams was to get spectra of the distant

supernova candidates, making sure that they really are supernovae, and we wanted the Type Ia supernovae— the exploding white dwarfs. I was also responsible for getting the red shift of the galaxy in which they're located, that is the amount by which the universe has expanded during the time that the light has been traveling toward us. So, the supernova brightness tells us the distance and the redshift tells us the expansion factor. By plotting the distance and slopeback time versus the expansion factor you get the expansion history of the universe. And from that we concluded that it's expanding faster now than it was five billion years ago, leading to this conclusion about acceleration driven by dark energy. And that was what was recognized by the Nobel Prize, so I'm very proud of my contributions to that project because without the redshifts, and without knowing that these were Type Ia supernovae, we would have been dead in the water. I was the one who was primarily in charge of that aspect of it.

In terms of something that I did myself and not as a team, I am proud that I took advantage of the opportunity that landed in my lap February of 1985 and immediately started looking at the data and analyzing the data and trying to understand what the data meant. I've seen other cases and in fact even in

my own case sometimes there have been exciting data I did not capitalize on because I didn't work on them right away and didn't realize that they were trying to tell something interesting. Sometimes you're lucky and sometimes you're not, but part of the key to success is in capitalizing on your lucky breaks and recognizing them when they're in the process of happening.

So it was a lucky break that I just chose that galaxy and it happened to have this weird supernova, but I didn't just sit around and not do anything. I was energized into motion and within two weeks we had submitted a paper to Nature on this discovery and its implications and that then led me down this path of studying supernovae. I was still interested in black holes and quasars and things but a whole new avenue of research opened up because I was ready to make this change and noticed that we had an interesting result on our hands.

BSJ: The concept of Carl Sagan's quote about how we are made from star stuff was very pertinent to our topic of death and dying, and how it relates to, literally, the death of the star bringing about new life.

F: You might wonder that all these elements were there to begin with. But they weren't. There was hydrogen, helium and a little bit lithium. That's basically it. The elements have to come from somewhere, and it's almost mind-boggling that we now know that the heavy elements in our bodies were generated in stars long ago. So, in other words, we definitely used to be part of a star. Nuclear reactions build up heavy elements from light ones.

Some stars have to explode, to get these synthesized elements out into space. It's not enough to synthesize them through nuclear reactions; you need to get them out. The supernovae are important in getting them out and in producing (either directly or indirectly) all of the heavy elements.

Studying this process of stellar death, especially violent death in the form of a supernova, informs us on the process of how clouds of gas get enriched in heavy elements and subsequently go through a new generation of star formation, followed by stellar death, and so on.

So by the time our solar system formed four and half a billion years ago, at least in some pockets of our Milky Way galaxy, enrichment up to a level of two percent by mass had occurred. So our sun is about two percent heavy elements. Earth is not a good representative of the composition of the universe. Sun is much more so. It's mostly hydrogen and helium, two percent of heavy elements. That took billions of years to get up to that point.

We understand that process pretty well—at least in its simplest form—so I can tell people without any real doubt



we came from the stars. And that's one of the key ideas that I tell my students in Astronomy C10. They have to know and remember that fact throughout their lives. Some day they might come back and if I ask them some obscure questions, okay if they don't remember. But, if I ask them where the elements came from, and they don't correctly answer, then I will retroactively fail them! They will lose the jobs that they got as a result of their good GPA at Cal! Obviously I'm joking, but it's such an important concept.

In the context of your topic, which is a really interesting one, coincidentally, it turns out that in June, I will be near Rome at a small gathering composed of philosophers, theologians, and scientists, discussing this very issue. The event is sponsored by the Templeton Foundation and there is a little seminar entitled "The Role of Death in Life." My job is to talk about this very issue and philosophers and theologians will talk about other aspects. But yes, the topic is concerning the astrophysical role of death in life.

BSJ: It's somewhat fascinating how physics is seemingly starting to replace philosophy and the explanation of the origin of the universe.

F: Philosophy and science have a very interesting love-hate relationship. Quite a few scientists really like philosophy, and quite a few really despise it, and say it has no business in any rational discourse on the observable, experimentally-verifiable universe.

I personally think scientists and philosophers can co-exist and can have fruitful conversations with one another. I don't agree with one of my mentors, Dr. Dick Feynman at Caltech, who often belittles philosophy, actually saying there is no reason for it; there is no room for it.

But there are other scientists, like Einstein, who are deeply interested in philosophy and meaning of things at some ultimate level. You will get a diversity of opinions that I'm usually on the fence about. I run the middle line on that issue.

BSJ: Thank you very much for your time!