TO MARS AND BEYOND

Charles Elachi, director of NASA's Jet Propulsion Laboratory, previews the next spacecraft landing in search of life on the Red Planet

To illustrate the extraordinary scientific ambition entailed in space exploration, Charles Elachi used a sporting metaphor during a recent lecture at the American University in Cairo. This August, he said, the Jet Propulsion Laboratory (JPL) of the National Aeronautics and Space Administration (NASA) will attempt to land a mobile laboratory on Mars. The remarkable journey of the rover *Curiosity*, as the $2.5 billion lab is called, will take eight months to reach a destination some two hundred million kilometers from Earth. This feat of engineering, explained JPL's director, is the equivalent of a golfer teeing up in Los Angeles and driving the ball all the way to Cairo—and making a hole-in-one.

Elachi's talk in Cairo, part of the Zewail Foundation Public Lecture Series in Science and Culture, was also a homecoming to the Middle East. He was born and raised in Lebanon, before going off to earn degrees in everything from engineering and geology to business administration in France and the United States. He is a vice president and a professor of electrical engineering and planetary science at the California Institute of Technology, which manages JPL for NASA. He joined JPL in 1970 and as director since 2001, leads an institution of five thousand employees with an annual $1.6 billion budget that has long been in the forefront of man's search for knowledge about the universe. In JPL's latest mission, *Curiosity* will scoop up rock samples and perform on-site tests on them for signs of organisms—and possibly the first proof that life existed on another planet in the solar system. *Cairo Review* Managing Editor Scott MacLeod interviewed Elachi at JPL's headquarters in Pasadena, California, on February 29, 2012.

▷ Charles Elachi in his office at NASA's Jet Propulsion Laboratory, Pasadena, Feb. 29, 2012. *Scott MacLeod for the Cairo Review*

CAIRO REVIEW: *Are those your "toys" on the shelf there?*
CHARLES ELACHI: Yes, these are models of all spacecraft which are flying now or which I was involved in. We have about twenty-three spacecraft operating from JPL. If you take NASA, it's much larger. But these are all from JPL, and they are all crafts out in the solar system: from the Earth's

orbit all the way out to the edge of the solar system. And they are all being monitored from the building just behind us. That's where we have mission control. So, we are the center of the universe here.

CAIRO REVIEW: *So, is there life on Mars?*
CHARLES ELACHI: I don't have proof. I would say that there is a high likelihood that there is some kind of life in our solar system—either in the present or the past. The reason I say that is because Mars basically at one time had a very similar environment as Earth. Now you ask, why do I say that? Well, from our missions here we believe that a few billion years ago there was actually a liquid ocean on the surface of Mars, which may imply that the temperature was pretty good—if it was liquid. That's what we see in the rocks and chemical composition of the rocks. So, the immediate question is: if we once had oceans on Mars and the temperature was similar to ours, could life have evolved in it? And the answer would be equally exciting either way. If it did evolve, the question would be: what happened to it? Why did the environment change and the ocean disappear? Can we see any signature of something left from that time? But if life did not start, then that's equally puzzling. Why did it start on Earth but not on Mars? So, the key objectives we have in all our missions, particularly the one that's heading to Mars now, which will arrive in August, are: Was Mars habitable? Does it have the chemical material which could allow life to evolve? We aren't looking for a bug or anything like that—but if there are the right chemicals, if there are long chains of carbon. Are the materials on Mars similar to that on Earth, which could then lead to life evolving if you had the right environment? So, in a sense, it's like Sherlock Holmes trying to see all the signatures that could have led to life. Now, we might be surprised and we might find some old cells in the rocks, and that would be a very positive surprise.

CAIRO REVIEW: *Talking about "life," do you mean just an organism, or do we mean people walking around, and animal life?*
CHARLES ELACHI: No, we're talking more about organisms at that time. We are clear on Mars now; we know there is nothing on the surface because we have mapped it, in extremely high resolution. So, if there was any activity or life on the surface we would have detected it. Now, there could be some below the surface, but that would be organisms like those we find on earth. You go to an oil well and you'll find an organism, you go to the water table and you'll find an organism. So, that's more likely when we say "life." And we're finding it's not only Mars, [but] particularly satellites of other planets, like Enceladus, which is a satellite of Saturn, Titan, another satellite of Saturn, and Europa, which is a satellite of Jupiter. We can see now they have oceans below the surface. So, the question is: could life have evolved in these oceans? I mean,

if you have a huge frozen lake, the top is frozen but then you can have life in the liquid ocean below it, like you have in Antarctica or in the Arctic. So, what we've found in the last decade is that water is much more common in the objects of our solar system than we originally thought, in the past and in the present, and that organics exist. If you have liquid water then that means the temperature is very comfortable. So again, it begs the question; could life have evolved the same way it started on Earth? And which track did it take? Like, it could've evolved, but took a different track, or started evolving then stopped? So, these are the questions we're trying to answer.

CAIRO REVIEW: Curiosity *will land in August. What is the prognosis for that? You had a lot of failures in these missions.*

CHARLES ELACHI: When you are exploring, it's always a challenge; when you're doing something for the first time. There is always a risk of many things that could happen. We have a very good record over the past ten years, not only to Mars. We've had almost twenty missions and all have been successful. We hope we can keep that trend going. It [*Curiosity*] is a very sophisticated and complicated mission. We are highly confident that it will be successful, but there is always a small chance that something could go wrong because there are so many things that have to go right. And then you have the environment on Mars as well, which is a fairly unknown environment. You might get a gust of wind [during spacecraft landing] or something else that we hadn't expected could happen. So, there is always a small risk. But as of now, the spacecraft is doing well; it's almost halfway to Mars. The landing is scheduled for 9:30 a.m. on August 6, Cairo time. And it'll be transmitted in real time on our website and on CNN. So, you will know as soon as we know how well, or not, it's working.

CAIRO REVIEW: *What are the outer limits of your imagination on what you're going to get on this mission?*

CHARLES ELACHI: There was much debate in the science community to select the site where we will actually be landing on Mars. The science community, with hundreds of scientists involved, started with hundreds of sites. Each one had different features and they had to work their way [through them all] in order to reach a consensus on the specific site that we now have. The chosen site, the reason it's interesting is because it's at the bottom of a hill. When I say a hill, it's really a mountain about fifteen thousand feet high with layers of different material, which will allow us to learn about the history of Mars. Just like what you see in the Grand Canyon; there are different layers of different rocks. So, we are going to be driving up the side of that hill and taking samples from its different layers. Many of these layers have the characteristics of what you find in the bottom of dried up lakes; phosphate, chloride, and so on. So, as we come across areas of interest,

we take samples and analyze those samples and see what its composition is, and we will be looking—as I said—for organic material, or material which could mean that life could grow in those areas. So, we are really doing two things. One is to find the characteristics of the area which might be habitable. And number two, as we go up the side of the hill, the side of that mountain, it will give us a history because bottom layers are older than upper layers and so on. It's like you'll be going through a chapter of a book, one page at a time, and hopefully write the story of what happened in that region. The mission is scheduled to go for two years, but it'll most likely go much longer than that. (The rover we have now on Mars was supposed to work for ninety days, and that was eight years ago.) So we could now drive to the fifteen-thousand-feet-high top of the hill. If we do that, it'll be driving slowly. So, we would do it at one hundred meters a day. We will drive, look, examine the rock, and maybe take samples. A scientist decides whether we take samples or not because of the limited number of samples we can analyze. We are confident about analyzing twenty-five to thirty different samples, but we'll probably aim for about one hundred samples. We will have to select them carefully so we don't consume the material and everything in the first month.

CAIRO REVIEW: *And what would you learn from that?*
CHARLES ELACHI: Hopefully it will tell us, number one, what the chemical composition of the material is. Number two, whether the composition at some time in the past was an environment similar to the Earth's environment, and do we find organic material? If we find organic material, then that will tell us immediately that we have all ingredients for life which were present. Will we see life there? That would be a pleasant surprise. We don't know for sure.

CAIRO REVIEW: *You mean a living organism?*
CHARLES ELACHI: No, it could be an organism which evolved then died. You look in the rocks and see organisms from a billion years ago, but they are not alive today. So, that would be equally exciting, because where we see them in these rock layers tells us what date or what period that organism would have been alive, and why it became extinct.

CAIRO REVIEW: *Till now, there is no confirmation of that kind of organism life on Mars.*
CHARLES ELACHI: That's correct.

CAIRO REVIEW: *So, if you find an organism...*
CHARLES ELACHI: That would be a huge scientific event. Who knows? We always get surprised.

CAIRO REVIEW: *What have you learned from the rover missions?*
CHARLES ELACHI: The ones that we have there now are more like roving geologists. They are the ones who have demonstrated by analyzing rocks that an ocean existed in the past. Where we stand today, we know that there are polar caps on Mars. We know that they have water in them, but they're all frozen. We know there is a drainage channel—which looks like in Egypt, you know, when you go to the western or eastern deserts, you see drainage channels but they are dry. But that says at some time in the past there were rivers that made those channels, you know, on Mars. So, the big puzzle is, where did this water go? Was it on the surface for some period of time? We know from the rover that, at some past period of time, water was on the surface. So, the puzzle now is where did it go? Did it all evaporate or is it in water tables below the surface? So, on future missions, not this mission, but future missions, we want to be able to look below the surface either with a radar system, or from the surface with a sounding system or with drills, to see if we can access that water. Now, when we landed Phoenix a few years ago, pretty close to the pole, we did see ice, just literally a few centimeters below the surface. We were able to expose ice. The question is: at lower latitudes, would that water be in ice form, or could it be that if we drill one hundred meters down, just like in the desert in Egypt, you actually get to a water table? That would have two implications. Number one, are there any organisms in that water? Number two, could it be a source for when we send humans [to Mars] in the future? Then you would not have to take your water with you because there is a place to access water there. That could make a huge difference because if you want to spend six months there, then you need to take a lot of water with you. The other benefit of water is that you can break the water molecule to get oxygen and hydrogen then you can use that for fuel for the spacecraft to return a human back [to Earth]. So, the presence of water is a key element, and that's one of our long term objectives: finding where it is, if it's accessible, what's it made of, can we make it, can we drink it, and so on.

CAIRO REVIEW: *What have we learned about Earth itself from these Mars missions so far?*
CHARLES ELACHI: There is no direct learning, but [in Mars] we have a model of a planet that somehow evolved differently to our planet. So, if we understand how it evolved, this could shed light on the differences, because one of the key questions we have is, how did our planet evolve? How did life start here? What were the ingredients that were so amenable to have life put here? One method of science is that you look at something that had a positive result and you look at something that started with the same initial conditions and got a different result, and you try to understand the differences between them. So, we are still early in the stages of understanding.

CAIRO REVIEW: *What is the potential value in what you can learn from Mars about life on Earth?*

CHARLES ELACHI: If we could understand why life became extinct on Mars, if that's the case—if it started and became extinct—that could have an implication on how we manage our own planet to make sure we don't end up in the same situation. Also, it could be a possibility that at some future time we could modify the environment on Mars and make it more amenable for life and that could be a place for humans to go, another place to explore and survive. And then you have the benefit of technology. Every time we do these missions, we have to develop advanced technology to do them. And then some entrepreneur will figure out a way to use that technology on Earth. To give examples, cell phones, GPS, infrared cameras, and so on. These are all side benefits. The approach that we find more successful in science and technology is to take a very tough problem and put smart people to work on that problem. They have to invent new things. And as you invent it, entrepreneurs will have access to this technology and will use it. So, that's what we find here in the United States as a successful model of how to advance technology. Nobody thought of the Internet! When people started developing the Internet, which was purely for communication between scientists, nobody had any idea that it would become what it is. We can't live without it now. Who knows when the invention comes out that could change our lives ten years from now?

CAIRO REVIEW: *Putting a man on Mars?*

CHARLES ELACHI: And a woman.

CAIRO REVIEW: *Of course!*

CHARLES ELACHI: The way it was laid out was that NASA's long-term vision was always to go beyond Earth's orbit. I mean, we've already put a human in Earth's orbit; we've gone to the moon. But that's as far as it is. So, the long-term vision for NASA was to expand the reach of humans by robotics, which we do now all the time, and then in time to enable humans to travel beyond Earth's orbit. Mars is a natural place. Also asteroids, and other locations. So, one of our goals is, twenty years from now, thirty years from now, one goal is to enable humans to go to Mars. Either to go in orbit or to land on the surface. Moving backward from that, if we say we want to send someone to Mars in the late 2030s, then what things do we need to do now, to make sure that will happen? We need to learn more about the environment around Mars, we need to see what the scientific questions are. Where would we send them? It is a huge planet; it's the same size as Earth without the oceans, the same size as the land mass on Earth. So, first you would send robots and say, "Well, this area looks much more interesting than this area," or, "This area has methane being emitted from the surface, maybe there is some

life activity." So, the goal of the robotic missions is number one, to fully explore Mars so we can select the right sites. And number two, it's kind of like a dry run. If we want to land, rove around, take off, and come back, then it's a good learning experience before you actually send a human, which would be more expensive and, you know, have lives of people involved. And that's the same thing we did on the moon. On the moon, we had almost twenty robotic missions to the moon before we sent a human to it, which allowed us to characterize and learn how to land, take off, and come back.

CAIRO REVIEW: *What's the value of actually having a human being go to Mars? Given the amazing talent of the robots?*

CHARLES ELACHI: Rovers can do a lot, no question. But still, they cannot make a judgment. There are many things to do and currently people on Earth decide them. Considering the signal takes twenty minutes round trip there are a lot of things that are hard to do because of that time delay. If you have human there, he can make decision in real time. So, I think it's going to be a combination of humans and robots. Robots are very good to go to hazardous places the first time, to explore before you take the risk of sending a human. Humans have judgment, which is very hard to add to the rover particularly because of the time delay that we have between the two places.

CAIRO REVIEW: *Can you give an example of that? What kind of judgment do they need to make on the spot?*

CHARLES ELACHI: Like if you're drilling for deep water; doing that completely by robot will be a challenge. It could be done, possibly, but it would be extremely challenging to do it. If something breaks, we wouldn't know about it for ten minutes, then we'd sit down, think about it, and then send a command, but it might be too late, if something is already going wrong. So the way we do it now, as soon as something goes wrong, you stop, you don't do anything. And that's not an efficient way of doing things. If you have a human there, they can react in real time and find solutions. We've already had examples, like when we repaired the Hubble telescope. That could've been done robotically, but it was much easier in that case because we had a human. It was much more efficient to do that repair with humans. And then there is the ultimate goal of human exploration, of actually being there. So, that adds an additional feature to it. So, it's not driven by science, it's driven by having a goal in the long term of possibly sending more people to Mars. And that would be an extension of Earth. So that's really the benefit of it.

CAIRO REVIEW: *What's the outer limit of your imagination about what man would do on Mars?*

CHARLES ELACHI: Ultimately, we could transform the environment on Mars and have it habitable like Earth. We could send colonies to Mars. That's an expansion like, you know, we expanded to the Americas after Columbus. I mean, it's a little bit different. There were people in the Americas and we don't expect there to be people on Mars. So, that's possible: it could be an extension of Earth.

CAIRO REVIEW: *That's not science fiction?*
CHARLES ELACHI: No, it's not. It could be done. It's at the edge of science fiction, but if we go back fifty years, what we are doing today was science fiction fifty years ago. People didn't even dream of having rovers on Mars. It was all science fiction. People did dream of it, but it was purely in the domain of science fiction, having rovers on Mars, going to Europa, watching volcanoes on Europa, and so on. Now it's common for young people to just go on the web, google Europa, then "fly" over Europa.

CAIRO REVIEW: *You mentioned in your talk in Cairo that the last generation or two have made tremendous advances in science.*
CHARLES ELACHI: When I was in high school, the planetary chapter was just a couple of pages and pictures of the planets were just little dots of light and that's what we knew about that. When my daughter was in high school, she had CDs where she was flying over those planets. So that was just one generation. We have changed the whole textbook. And I never imagined when I was in high school that all of this would happen. So, we have to stretch our imagination to what my grandchildren, when they are in high school, what they'll be doing. I don't know. But I think it could be they'll sit down and operate robots on Mars for their high school project. Or somebody doing a PhD will be given time to go and drive rovers on Mars, do some drilling, do analysis on another planet, on Europa, or something like that. So, it could be that if we have interplanetary Internet then anybody could sit down and communicate immediately with his rover or with a human, if they're there. And then you have an exchange on Twitter or do something with people on other planets. So, that's all possible in the next thirty to forty years.

CAIRO REVIEW: *If there's money. It seems that the more imagination you have about where you can go, the budget seems to shrink.*
CHARLES ELACHI: It's always a challenge.

CAIRO REVIEW: *Science needs funding to achieve the goals you have, but this is a matter of public expenditure. How do you assure the budget is there?*
CHARLES ELACHI: This is always a debate: how much you invest in the future versus investing in today's problems. I'm sure many people asked Thomas Jefferson,

"Why are you sending Lewis and Clark out west, for heaven's sake? It's costing five thousand dollars. We could solve more problems of poverty on the east coast." But he invested in doing that, and opened a whole new frontier for the United States. I'm sure the same thing happened with Columbus. I think the key point is that we are convinced that the future of economic growth anywhere in the world is based on gaining new knowledge. And we can't predict this knowledge ahead of time. So I think if we want to solve our problems today, we have to invest in gaining more knowledge for the future. That's how you get yourself out of the problems of today. So, fortunately, in the U.S., we have in general, despite all the budget issues, we have a fairly receptive Congress and administration, which do believe that the investment in science, technology, and gaining knowledge is very important for the economic health of the country. So, in the end, I think the society that invests in knowledge is the one that will really thrive in the future.

CAIRO REVIEW: *There have been questions about the value of the space shuttle, whether the results were a good return on the investment. Is that a valid comment in terms of the short perspective?*

CHARLES ELACHI: The way I look at it, when investing in knowledge, some are willing to pay a lot of money and some might not pay a lot of money. The purpose of the shuttle was always to build a space station, not just to build a shuttle. It's basically the truck that allows you to build stations in Earth's orbit. So, the station is built and now the challenge is to conduct research in the space environment to see if there is any benefit from it. Are there any new drugs you can develop, any new material that in zero gravity you can develop? So, I think the jury is still out on whether it's a good investment or an average investment or not a good investment. But again, as I said earlier, when we invest in technology and knowledge, we need to expect that some of these investments are not going to lead to any major development. So, for me, that's not usually a factor. The factor is we should do the best we can to invest in knowledge and then hopefully a few developments will materialize and we should be happy with that. There are a lot of applications, to give you an example, that were direct benefits from the shuttle. Today we have 3D images of the Earth, on the Weather Channel or for topographic mapping. When you see 3D images of Egypt, for example, all of that was acquired from the shuttle program. People don't associate them, but this was something we built at JPL. We put it on the shuttle, we flew it, and we generated three-dimensional maps of the whole world in digital format, which pilots now use. People who install cell phone towers actually use our 3D imaging. So, all of that came from a mission we flew on the shuttle. People don't remember that because it was twenty years ago, but that's one example of a benefit.

CAIRO REVIEW: *Can you talk about President Obama's plan for the Space Launch System (SLS)?*
CHARLES ELACHI: There are enough companies which know how to take people and cargo from Earth to Earth's orbit. And the idea is to make that a commercial endeavor. And then we can have NASA focusing on going beyond that orbit, be it with humans or as we do now with spacecraft. To get beyond the Earth's orbit, and send a human beyond this orbit, you need two critical things: a habitat for the people, that's what we call the CEV, or Crew Exploration Vehicle. And the second, when you send a human, you need to take a lot of equipment so you need bigger rockets than we have now. And that's what the SLS is. These are the two foundational developments to being able to carry humans beyond Earth's orbit, not only to the moon, but ultimately to Mars. That launch vehicle will need to be even more powerful than Saturn V, the launch vehicle that took astronauts to the moon. So you need that kind of power for a launch vehicle to carry human habitats beyond the Earth's orbit.

CAIRO REVIEW: *And even beyond Mars?*
CHARLES ELACHI: Yes, it could be. We are now looking at how to send a robotic mission using this heavy launch vehicle, particularly when we go to the outer planets beyond Mars. We don't yet have rockets powerful enough, so what we do now is we launch a spacecraft and we have it fly by, say Mars, or do multiple fly-bys of Earth, and use gravity to help us, to speed it up. It's called "gravity assist" in technological lingo. And that's why it takes seven years to get to Saturn. If we have a heavy launch vehicle, we can get to Saturn in about two and a half years. So, it would cut the trip by a factor of two for a robotic mission. So, that could enable us to send more robotic missions and further than we have done in the past.

CAIRO REVIEW: *You talk about how science produces advances for humanity. What about the survival of humanity? Stephen Hawking made his famous comment, "Maybe we have a thousand years left on this planet."*
CHARLES ELACHI: I don't know how he came up with that number.

CAIRO REVIEW: *Do we depend on space exploration for survival?*
CHARLES ELACHI: Well, there are a number of aspects. There is the aspect that if something really bad happened on Earth, we could go to another planet. Or there is the aspect if we see an asteroid heading for Earth that could destroy life here, is there a way to divert it? We know for a fact that there have been major impacts on Earth over history. Every crater you see means something hit Earth. Now, most of them are small, but some of them are huge. The whole Gulf of Mexico was formed by a

huge impact on that area, and that's what people believe caused the extinction of the dinosaurs. Some event like that could happen again. It's not going happen tomorrow, but something like that might happen in the next few hundred or thousand years. That could be possible. So, some of the things we are looking at are, number one, to track all of these objects and know if it is possible that one of them might hit the Earth. Number two, if we find that some of them have a high likelihood of hitting the Earth, if we knew that early enough, we could divert it and make sure it avoids the Earth. So, that's one other benefit, it could be kind of a protective shield if you want to think about it that way. And another one is, remember Earth's orbiting satellites, which work on monitoring our planet, looking at what damage we are doing, the carbon dioxide emissions, the warming of the planet. That's all part of the space program. There is a network of satellites in Earth's orbit, they are learning about how we can protect ourselves if there are asteroids which might hit the Earth. There is also the benefit of learning about other planets. We know what led Venus to be so hot, because it has a lot of carbon dioxide. Could our planet become like Venus and become inhabitable? All the way to, if things go wrong, is there a place we can go to continue humanity? So, I think there is a whole spectrum which benefits us directly. But it won't be tomorrow. It won't make the person who doesn't have food on their table happy, because they are worried about tomorrow. But we also have to worry about the longer term.

CAIRO REVIEW: *We know there were oceans on Mars, and we know they are not there now. Is that possibly from global warming? Can we learn something about global warming?*

CHARLES ELACHI: We don't know for sure about that. We know that on Venus, it was a result of global warming. Venus is very hot now, it has a lot of carbon dioxide. What we call the 'greenhouse effect' is happening on Venus. Mars, we don't know for sure, because it's much colder now. Mars is not having any global warming effects and we don't know exactly why that is. There are different theories. We know the climate on Mars changed but we don't know the reason behind it. Is it that Mars kind of drifted away in its orbit? Or that the sun was warmer in the past and is cooling now? Maybe Mars was once a friendly place and Earth was not, and then the sun cooled and Mars became too cold but the Earth became a little bit warmer? These are the things that we don't understand at the present time.

CAIRO REVIEW: *I take your point of the need to explore for the future, but what about the current challenges? A huge expenditure is required to go on a Mars mission. How can you weigh that against fighting the poverty on the planet that we live in today?*

CHARLES ELACHI: Let's first start with a reference. The budget for NASA in the United States is 0.3 percent of the national budget. A comparison we give is that it's like you buying chewing gum every day. People think it's huge, but it's a minute cost relative to all other expenditure. And we still believe that this is a very good investment for gaining knowledge. If you take all research that the U.S. government funds, it amounts to just 3 percent of the national budget. So, this is not the way to solve poverty. You can't take your 3 percent and think you can solve the whole thing. This is the investment for the future. For a country to put 3 percent into investment for the future, despite its day-to-day issues, I think that's a great trade-off. I don't have the magic formula—maybe it's 2 percent or 4 percent—but I believe that the investment being made now is toward the low end because potentially, in the longer term, it could have a great impact.

CAIRO REVIEW: *Some people argue that we can't be stingy when it comes to investment in space technology, because we need science for our future and that the U.S. is actually falling behind in science. Would you agree with that?*

CHARLES ELACHI: There is a concern. It's a combination of, not that the U.S. is falling behind, but that other countries are moving at a faster rate. The U.S. made a tremendous investment [to space technology] during the 1950s, 60s, 70s, and 80s, which made a huge difference. Now other countries, like China, see what's happening in the U.S. because of education and investment. Look at the economy we have here. Western Europe saw the same thing. India. So, they are putting more and more investment in that area and they are kind of catching up. The challenge for us in the U.S. is to keep running as fast as we were running before, because the world is becoming more competitive. With the Internet, knowledge is getting everywhere. So yes, it's a concern and it's a combination of, not only investment in space, but investment in research, investment in education, and investment in technology. So yes, we have a concern that, even when we are still ahead of everybody else, the rest of the field is getting much closer to us than in the 1950s and 60s. So yes, it's an area of concern.

CAIRO REVIEW: *You mentioned China. Is the U.S. facing another 'Sputnik moment' with the advances the Chinese are making?*

CHARLES ELACHI: I'm not sure if it's a Sputnik moment. But, yes, China is catching up. They have a much larger population than the U.S. and economically they could become a very major competitor. So, we should continue to collaborate with China but we need to learn to run faster. That's where the investment comes from. So, it's not a matter of slowing China down, because it benefits everybody when economic wealth is everywhere. But to remain a leader, you just have to keep running faster.

CAIRO REVIEW: *What do you make of China's program? They made a lot of announcements about huge investments.*
CHARLES ELACHI: Yes, I know. It's a serious program and I think they have a lot of capabilities in China. But we have to wait and see. Now, it's still heavily military-oriented. So, we have to wait and see whether they will get there. But they have a lot of capabilities that they are developing.

CAIRO REVIEW: *How much potential is there for U.S. collaboration with China? Is the U.S. really a rival of China in this field?*
CHARLES ELACHI: That's in the domain of politics. It's interesting. You know, we collaborated with Russia during the Cold War. We were against each other and rockets were pointed at each other, but we still collaborated. So, I think, always, collaboration opens you. In fact, it helps defuse tension, because you get to know other people, you find out they are similar to you, they have kids, they care about their family, and so on. So, I think collaboration, if done properly, is always to the benefit of everybody.

CAIRO REVIEW: *In the U.S. science community, how much collaboration is going on with the Chinese program?*
CHARLES ELACHI: Not very much, I should say. It's still at a very early stage and that is, as I said, in the domain of politics. But we have a lot of collaboration with India, or we are expanding our collaboration with India. Russia, we still have a lot of collaboration and we built the space station together—thirty years ago that would have been unthinkable. So, I could imagine ten to twenty years from now that relations with China will be much better, we'll start having more confidence and it will grow.

CAIRO REVIEW: *As you look at it, not as a politician, but as a scientist, is there really reason to be concerned about an arms race in space vis- à-vis the Chinese? You mentioned they are very security-oriented in their program.*
CHARLES ELACHI: No, I wouldn't be very concerned about that if it's done in the right environment. Again, you don't collaborate with them on a ballistic missile. You collaborate on exploring Mars. That collaboration wouldn't have any implication for security or anything. So, I think there are a lot of areas where you can collaborate on peaceful things and not for military purposes.

CAIRO REVIEW: *In all the advantages you mentioned in the space program, you didn't mention advantages to the U.S. on the military side. Is that a benefit to the U.S. space program that Americans need to know about?*

CHARLES ELACHI: Clearly. No question about that. There is always benefit when you develop a new capability. You can use it for peaceful purposes or you can use it for national security purposes. And even national security could lead to a peaceful thing. When we and the Russians were competing, the fact that we knew what they were doing because of our assets in space, helped to make them a little bit more careful about what they did. And as you know, the nuclear treaty, the foundation of it is that we tell each other what we are doing. The worst thing to happen is when I'm against you and I don't trust what you might be doing to harm me. But if you show me exactly what you're doing, that could create a little bit more confidence in building good relationships. So, no question, developing space capability has been used and could be used for creating a peaceful environment between nations.

CAIRO REVIEW: *One of the things that struck me in your talk in Cairo was when you mentioned that the sun will definitely explode. And it made me think that the Earth will eventually be totally wiped out.*
CHARLES ELACHI: But I said this may be a few billion years from now. I'm not losing any sleep over that.

CAIRO REVIEW: *It does raise questions of a spiritual nature. As scientists, does this knowledge you gain about the future of the Earth reinforce spirituality or does it make you feel more inclined to think that this is just science?*
CHARLES ELACHI: There are two steps. The reason I don't worry about the fact that the sun will explode is that life is probably all over the universe. You have billions of stars and probably billions of planets and most likely many planets have life on them. So, it's not the end of life in the universe. It might be the end of life in our neighborhood, but not in the universe. Number two, about the question of belief, people do say when a scientist gets more knowledge, he becomes less of a believer. I'd say it's the reverse, because the more you gain knowledge, the more you are awed by the universe around us. And you have to believe that there is some kind of power that made it happen. If there is a God that's more a question for religious debate—but the belief that there is something really overwhelming that created this universe makes you believe more. When you look at billions of stars and galaxies, you ask "How did that happen?" It just didn't happen by itself. If that leads to God or something different, I don't know. But it makes you believe in a higher power.

CAIRO REVIEW: *There is political pressure, at least in our part of the world, in the Middle East, but also in the United States from religious fundamentalists about creationism versus evolution. Are scientists affected by that? Does that pressure affect our progress in science?*

CHARLES ELACHI: Not necessarily. I mean the way I get asked this question particularly in the Middle East, I keep saying that knowledge is for the brain and religion is for the heart. And they don't contradict each other. So, in my mind, gaining more knowledge doesn't go against religion at all. And being more religious doesn't go against knowledge.

CAIRO REVIEW: *How does it feel to have an asteroid named after you?*
CHARLES ELACHI: Ask my daughters! They are very proud of it. It's "4116 Elachi," I think, or something like that, I'm not sure.

CAIRO REVIEW: *As a scientist from the Middle East, how do you see the education challenges in the Arab world?*
CHARLES ELACHI: I think that's a very good topic. I personally believe that there is no reason the Arab world cannot be as scientifically capable as the U.S. Look at people like Ahmed Zewail, myself, Farouk El-Baz. We were educated in the Middle East, we have the same genes as everybody in the Middle East, but we came to the U.S. and were given the opportunity in the U.S. to strive. So I think the challenge in the Middle East is for the government and industry is to provide young people the opportunity to start, by investing in research, investing in education, investing in technology. And people in the Middle East can strive as much as other places. There is no monopoly on being smart or being knowledgeable. It's really more a question of the opportunity and the Middle East has a lot of potential. As you know, Saudi Arabia has a lot of investment in advanced universities and research centers like the King Abdullah University of Science and Technology and King Fahd University of Petroleum and Minerals. That's what Ahmed [Zewail] is trying to do with his foundation [in Egypt]—to provide an opportunity and a place for young people to go and do their research. And I think they can strive like anywhere else. You just need the political environment and will, societal will, to actually invest in knowledge and new technology.

CAIRO REVIEW: *Do you watch sci-fi movies?*
CHARLES ELACHI: I'm not a science fiction person. I don't know why everybody thinks I'm a science fiction person, but I'm not. I don't read science fiction books. I liked *Star Trek* and *Star Wars*, but more because of the fun of watching than anything else. I was at a dinner with one of the actors from *Star Trek* [who played] Jean-Luc Picard, and he wanted to meet the director of JPL. He said, "I do science fiction in the movies. You do it in reality." So, yeah, I live in it. So for me, maybe that's why it's not science fiction because I think my normal job is doing these things.