THE BROOKINGS INSTITUTION

THE FUTURE OF THE U.S. SPACE PROGRAM

THE A. ALFRED TAUBMAN FORUM ON PUBLIC POLICY

Washington, D.C.

Wednesday, May 14, 2014

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The Scientific Community's Most Important New Discoveries:

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P R O C E E D I N G S

MR. WEST: (in progress) -- he would have taken much better care of himself, which I thought was very good advice -- although I also think, you know, if you live to 90, by definition, you've taken good care of yourself. But I think that's a great lesson for all of us.

Today's forum is going to focus on the U.S. space program. Space exploration long has been a symbol of American inventiveness and discovery. We've seen a number of exciting discoveries that have transformed our understanding of the universe and our solar system. We've learned about the age of the universe, its development, the history of Mars, and asteroids that have the potential to destroy us, among other things.

Yet, despite the many contributions of the space program, there are a number of questions as we move forward into the future. This is no longer your grandfather's space program. Increasingly, we are seeing commercial firms launch satellites, supply the International Space Station, or even offer the prospect of space tourism in the near future.

So, we're going to ask, what role should private companies play, and what should the relationship between them and NASA be? How should government contracts be awarded, and should there be competitive bidding on major contracts?

We'll also be looking at the question of scientific discoveries, and what we have learned in recent years, and how we should think about our future priorities in this area.

So, this morning, we have two different panels that bring together experts from the private sector, NASA, and academia. They come from different backgrounds, and they're going to help us examine the economic benefits of the space program and the scientific discoveries that have come out of the space program.

So, our first panel is going to look at the role of the private sector in the space program. So, Adam Harris is with us. He is vice president of government sales at SpaceX. He is responsible for implementing and overseeing SpaceX's interaction with federal agencies. Prior to joining the company, he most recently served as staff director of the House Select Intelligence Oversight Panel, on the Appropriations Committee. And he has held the position of space budget analyst on the professional staff of the Defense Appropriations Subcommittee.

Antonio Elias is executive vice president and chief technical officer at Orbital Sciences Corporation. He has worked at Orbital for almost 30 years, and previously, he was executive vice president and general manager of Orbital's Advanced Programs Group, which he has led since its inception in 1997. And earlier, he served as the company's chief technical officer and as corporate senior vice president. And in 2001, he was elected to the National Academy of Engineering.

John Roth is vice president of business development at Sierra Nevada Corporation's Space Systems. He's responsible for new business acquisitions and customer relations for all the product lines. He's served as president of Microsat Systems from 2002 until its acquisition by Sierra Nevada in 2008. And prior to that, he was vice president of Electronic Combat Business for Litton Advanced Systems.

So, I'm going to start with Adam, and just ask about the economic benefits of space exploration, and how private companies fit into the U.S. space program.

MR. HARRIS: Thank you very much. First, I'd like to thank the Brookings Institute for holding this forum.

And I want to talk about two things. One is how SpaceX has worked with NASA under two commercial programs: the commercial cargo program and the commercial crew program.

And then the second, I want to talk about how our industry has benefitted from technology; how technology has been advanced in the sector due to the space program.

So, first, one of the things that SpaceX has done -- so I work at SpaceX. We're a company that has the Falcon launch vehicle and the Dragon spacecraft that is currently attached to the International Space Station. We went up to deliver cargo to the astronauts this past couple of weeks, and we will bring cargo back from the International Space Station here soon so that there is a great scientific benefit to that platform.

And so, early on, NASA thought -- had a vision here of doing government contracting in a different way. And that way is, they have lumped it under this term "commercial." And they've had a number of programs. So, the first was the commercial resupply services program, which started out with thinking about, how would private sector deliver cargo to the International Space Station?

SpaceX has been a part of that program. We've thought it's worked very well. It's a model that we think NASA has successfully implemented, and we think the federal government ought to think about writ large, in that they offer the private sector fixed price, milestone payments, things that tell us what the vision is, where they want to go, and then they ask the private sector, what are the best ways to implement that vision?

And so as we developed our program at SpaceX, we developed a rocket; we developed a capsule. And those are both in use right now for delivering cargo to the International Space Station.

NASA is furthering that idea with the idea of launching astronauts. And so they have the Commercial Crew Program ongoing currently, and they're thinking about ways to take U.S. astronauts to the International Space Station. Currently, we're in the news this week, apparently with relations between the United States and Russia.

And we pay the Russians quite a bit of money to launch our astronauts to the Space Station; over $70 million per seat. And we think at SpaceX -- and we think at NASA -- there's an American way to do that, there's a better way to do that. And we're developing that, with a partnership at NASA. And so we think this new way of doing business with government contracting is a great benefit.

The second thing I kind of want to cover -- and then, quite frankly, I want to get to your questions, because that will be the most fun part of this session, I think --

MR. WEST: No, actually, my questions will be the most fun.

MR. HARRIS: Your questions will be the best; absolutely.

MR. WEST: I want to clarify that.

MR. HARRIS: They'll be the very best.

But the second one I want to talk about is our industry -- our space industry. And one of the things that we have found at SpaceX is, a lot of things within this industry have stagnated. There has been less technology development in this area with things like rocket engines. We rely on old technology, and we would like to push that technology. We would like to make technology advancements in the space sector.

And so one of the things we have found is, there have been massive advancements in places like the automotive sector. The automotive sector knows how to put out 20,000 cars in a month. And those cars have to last 10 years. And so we hear this term in the space sector, "human-rated." And so if you think of a car that, 10 years later, after you've used it for hundreds of thousands of miles, those safety bags in the safety systems and those mission assurances still have to work.

And we think there are a lot of lessons that can be learned from other industries. And so at SpaceX, we've been thinking about, what is it that the automotive industry does with manufacturing, and technology, and electronics, quite frankly? The package -- different ways of doing business -- and then applying them to the space sector.

The problem with the space sector is that when you get on orbit, the environment is really hard. It's very hard. You're in microgravity. You're in a radiation environment that you're not protected by the Earth's atmosphere. You're in a vacuum. There are lots of problems with operating equipment when you're in space.

And so you can't just take one technology and move it over, but there are some new ways of doing technology. One area that I would point to right now is 3D printing. 3D printing is a major advancement that SpaceX is trying to use to lower the cost of building, lower the cost of research and development.

One of the things we recently did over this past six months is, we printed an entire nozzle for a rocket nozzle -- 3D printed it. And then we took it to our test stand in Texas. SpaceX has a test facility in Texas. And then we fired that nozzle completely made by a 3D printer, which is amazing that we can do that with technology.

Now, this is an advanced way of doing 3D printing. It's with metal, and it's with better metals. A lot of the 3D printing technology relies on plastics and other ways of doing it, but this is a major technology advance that I think is coming to our sector, and going to make our space program better.

And I think those can be translated into both our launch vehicles, our spacecraft, and that will make a better result for exploration and for scientific advancement on the space side.

So, with that, I'm looking forward to your questions, and I hope we have a great discussion. I know your questions will be the best.

MR. WEST: Great. Thank you, Adam.

So, Antonio, what do you see as the economic benefits of the space program, and what role is Orbital playing in this?

MR. ELIAS: The space program, in general, has significant -- both general economy, as well as quality of life -- benefits. It's easy to forget that the main society advantage of GPS is not telling you where you are; it's telling you what time it is. And in particular, modern cellular telephone technology relies on the accurate timing provided by GPS, to synchronize the towers at a fraction of the cost of alternatives.

If, tomorrow, the GPS constellation were to disappear, the first thing that you will notice is, all of your fourth-generation cell phones would stop working. After that, the ATM machines and so on. So, there is a tremendous lack of understanding in general as to the benefits of space to society.

In terms of commercial applications, there is an 800-pound gorilla: the communications business -- soon to be expanded to digital communications.

Now, having said that, if you now restrict yourself to space exploration, you have to be careful on a number of things. First of all, what do you mean by "space exploration"? Because there is a distinction between human space flight and robotics exploration of science -- and, in general, science that is done through the means of space.

The second thing you have to be very careful with is the time horizon in which you make these predictions or these assertions. It is very different to say, what can space do for me in the next few months -- which is usually the timeframe of the public company when they have to declare dividends and report on income -- as to saying, what's going to happen four years from now?

Traditionally, forecasters of the future have been terrible at forecasting near-term advances in that they over-predict -- and terrible in forecasting long terms in that it under-predicts.

Let me give you an example: When Jack Schmidt, the only scientist to have gone to the Moon -- the geologist -- was sent to the Moon in the early '70s, the computer that guided the Apollo capsule had less computing power than my wristwatch. So, Jack Schmidt was there because the only way of performing geology on the Moon was to carry a human.

Today, you can carry an entire mass spectrometer to Mars, for a fraction of the cost, and the danger, and all that stuff associated with human space flight.

So, you have to be very careful, when you talk about space exploration, to distinguish between human space flight -- which has a number of characteristics, and advantages, and so on -- and nonhuman or robotic exploration.

So, in terms of the role of the private sector, I think it is dual. There's two ways in which a company such as Orbital can help in space exploration and can be helped by space exploration.

It can help space exploration by removing from the burden of performing that space exploration a number of tasks that were once heroic, such as launching a rocket, but now can be considered close to commodities -- both SpaceX and us developed our own launch vehicles. So, they're services -- not the hardware itself -- and have done so with significant amounts of private investment.

So, government, and public agencies, and generous philanthropists can concentrate their efforts and their resources in a way that's truly, uniquely exploration, that can then benefit society in general, and leave the private industry the more mundane parts. This distinction has not always been properly appreciated, and I think we have to educate our decision makers and their constituents about that difference.

In terms of the benefits to the company, certainly, it allows us -- it is an important part of our market, and it allows us to justify the investment to our owners and investors, to justify the development, and to bring in high-technology jobs to areas such as Eastern Shore of Virginia -- areas where local citizens were afraid to send their children to college, knowing that their children would then leave; they could not come back home and have a job that's married to their college education -- with activities such as our launches from Wallops, which have been made possible through our support of space exploration.

Now those parents are no longer afraid to send their children to college, knowing that there are good-paying, highly-qualified jobs at home.

MR. WEST: Thank you.

So, John, Sierra Nevada has a Dream Chaser Program that works with subcontractors, states, and universities. So, how does that program operate, and how do you see the economic benefits?

MR. ROTH: Right. Dream Chaser is part of the Commercial Crew Program that Adam talked about. It's an initiative by NASA that's a public-private partnership. It includes NASA funding, but, also, a significant amount of funding expected from the commercial companies in order to develop a new U.S. capability to get astronauts to the Space Station.

We’re one of the contractors that are working on that program. And that program has an economic benefit across the United States. It's not localized. We have almost 1,000 vendors/subcontractors supporting us on that program, in 31 states. We have 21 states that include small business and disadvantaged business participation. So, one program like that has a pretty far-reaching economic impact.

But more in general, what I wanted to talk about is, we are at an incredibly exciting point in the shift of the economics of space. Those of us in the space industry, we see it every day. I'm not sure the general public sees it as much. But we're going from a space economy that was really all government funded for 60 or more years, both military side and the NASA side, and we're in the midst of a shift to a commercial space economy.

And that's a huge shift. It's a huge shift in thinking about how we do space. It's a huge space -- huge difference in the targets that we go after in space, because, obviously, private companies have a much different view of what you need to get out of space than the science community does or the Defense Department does.

But you're seeing a proliferation of companies now that are doing things that NASA and DoD had no interest in doing -- or at least didn't put any funding against it, from mining asteroids to taking tourists up to hotels in space -- to a number of different activities. And then there are actually revenue-generating activities, such as pharmaceutical companies wanting to develop new drugs and microgravity, the science community wanting to develop cures for new diseases.

There's a huge thrust of new economic activity going on in space. And our company's kind of got a foot on both sides. We've been around for 50 years, so we're not a new company. We've been a 50-year aerospace company. 25 years, we've been sending things into space. And the interesting thing is, people are talking about commercial space as if it's a new thing. Commercial space has been around for decades.

Telecommunications satellites are commercial space. DirecTV is commercial space. XM Radio is commercial space. Commercial space is not a new phenomenon.

What tends to be new is the change between what they call old space and new space. And old space is an economy that's based on the government funding all the space activities, and new space, to me, is the economy moving towards entrepreneurs and commercial companies getting involved in space. And that's, I think, where the excitement is.

It's a changing in the funding sources. It's a changing in the economics, in terms of where you're trying to get benefit out of space. You're seeing a lot of billionaires that are coming in and funding space activities, which is really exciting.

I was joking at a conference a week or so ago that I had a four-step plan for getting a commercial space company started. Step one was, find a billionaire that's really interested in space, with a corollary that he's willing to become a millionaire. Right now, there's not been a huge show of that economic payoff, and we're all counting on it.

Our company is not only building Dream Chaser under the Commercial Crew Program -- and, of course, we see a very large market outside of just NASA sending astronauts to the Space Station. In the best case, NASA's going to buy from two to four missions a year to take astronauts to the Space Station.

Our vehicle is capable of 25 to 30 flights with a single vehicle. We don't want to do just two missions a year, so we're out, actively talking to a lot of commercial companies, a lot of international space agencies that are interested in getting more astronauts into space. We think there's a huge potential market beyond what NASA wants with our vehicle.

Another program that we're working on is, we build the rocket engines for Virgin Galactic, which is going to be -- we think -- the first commercial company to get an actual space tourism business going. Their business model is to go up over 100 kilometers, which is the end of space, go weightless for a few minutes, and then be able to come back down, land on a runway basically that you took off from.

The interesting thing about that--if you look at the economics of space--if you look at how many astronauts have gone to space since the beginning of the space program, for all the countries that have ever been involved in space--so anybody that's ever been in space, from the history of time, has been around 550 people, roughly.

Virgin Galactic has more than 650 people signed up to go to space on a commercial program. So, more people than have ever flown in space in the last 50 years are already signed up and waiting to go to the edge of space.

So, to me, it looks like there's a huge potential boom economy in space, and we're very happy to be part of it.

MR. WEST: Okay, thank you very much.

So, I'd like to throw out a question for each of you. And any of you who wants to jump in are welcome to do so. So, John was talking about the new models of commercial space, and we're seeing the possibilities of space tourism, mining asteroids for rare minerals, new drug manufacturing processes.

I'm just curious what each of you view as the greatest future opportunities in space.

MR. HARRIS: Sure. At SpaceX, we think the greatest future opportunities are new modes of transportation to orbit. That's why SpaceX was founded. We built the Falcon 9 rocket to service the International Space Station with the Cargo and Crew Program. We are building the Falcon Heavy rocket that will enable larger payloads to both Earth orbit -- but, also, beyond Earth orbit, to other planets and exploration.

So, we see NASA, and we are encouraging NASA, to expand this commercial paradigm, this way of doing business beyond servicing the International Space Station, but, also, thinking about their other missions. Are there ways that commercial companies can take over the transportation business for life sciences, for earth sciences, and for interplanetary sciences? And exploring the Moon, Mars, and beyond -- both with robotic missions and, perhaps, eventually, with human missions. And so we see that as a major development area.

The other area that is economically driving the space program in the United States is the commercial communications sector. And so those satellites that are broadcasting all of our communications around the world that are in orbit -- there's about 20 to 25 launches per year. And since the '80s, the United States -- in the '80s, the United States had 100 percent of those launches -- here, from Cape Canaveral, from the United States.

And a lot of those have gone overseas. We have lost the recipe in competing for those missions. And so we're attempting -- and I think this is major kudos to NASA and their program -- SpaceX wouldn't be where we are without the NASA supply missions to the International Space Station. But we're taking those rockets that we developed with that program and with NASA's partnership, and we're starting to win that business back to the United States.

And so our goal is to launch a majority of those communication satellites, here from the U.S., bring that industry back here, and to use our suppliers that are here in many states in America, and to launch those here.

So, we think that will grow this industry. We think that will cause this industry to blossom.

MR. WEST: Antonio, what do you see as the greatest future opportunities?

MR. ELIAS: Well, this meeting has been a little boring so far, so let me try and --

MR. WEST: You're going to change that up.

MR. HARRIS: You're going to jump it up?

MR. ELIAS: -- inject some spice by disagreeing, rather violently, with my colleagues in a couple of areas.

First of all, I absolutely do not see launch as the lynchpin to the future of space. Adam mentioned, quite accurately, that the art of launching, specifically propulsion, has been stagnating for the past few decades. However, I'd like to just disagree with him on why it has done that, and what's going to happen.

You see, on something like microelectronics, there's this little phenomenon called Moore's Law that says that every 18 months, the number of transistors per unit area or whatever doubles.

And if you look at what happens when you do that, and you think of the fundamental laws of physics behind semiconductors, rest easily, because there are several flips of Moore's Law available before we run into fundamental limits of just quantum mechanics or the principle of uncertainty.

Unfortunately, in rocketry, there are two parameters comparable to number of transistors per unit area -- specific impulse and structural mass fraction. And those are the ones that fundamentally determine the cost of launch to orbit.

And the problem there is that we have reached 98 percent of the limits of the laws of physics in one case -- the space shuttle main engines, in the early 1970s. And then the other case was the Atlas II launch vehicle that originated in the '50s. Since then, there have been no significant improvements in either specific mass -- specific impulse or structural mass fraction. And, yes, you can include some manufacturing techniques, but that is going to be the marginal benefits, at the most.

Now where I believe the money is, and the future is, and the benefit is -- and, again, I have to remind myself of my own warning that it's very different to predict the next two years than to predict the next 40 years. But, certainly, if you restrict yourself to the next two or three years, the improvements and the future is precisely Moore's Law. where has technology improved significantly? In microelectronics. What required a satellite the size of a school bus a few years ago can today be achieved with satellites that fit on top of the stable.

So, I see the great boom coming in things such as constellations of small, high-resolution satellites -- so many of them that the media, the public safety services, and others can have almost instantaneous, realtime video coverage of any spot on Earth that one may want to acquire.

Imagine what would have happened to that lost Malaysian airliner within minutes of the thing happening. A plethora of high-resolution small satellites could have been imaging entire ocean areas.

Similarly, today, we use communications, as Adam mentioned, to provide direct television, point-to-point communications, and others. But imagine if you reach a constellation of thousands of small satellites able to provide very high bandwidth internet connectivity, no matter where you are.

Now the odd thing, from the launch vehicle standpoint, is that you do not need any more launch vehicles. You do not need cheaper launch vehicles. A typical direct broadcast television company spends three percent of their costs on launch. A typical NASA mission, 12 percent of the mission cost is launch. A typical DoD mission, 18 percent of the cost of the mission is launch.

The highest example of impact of launch costs in the commercial valley of an enterprise is what SpaceX and us do -- launch to the Space Station -- in our case, about 35 percent of our costs. And it's blocked.

So, if tomorrow, you were to reduce the cost of launch by a factor of two, in the best possible case -- which is those places I just mentioned -- you would reduce your total cost by 17 percent.

But back to these applications that I was mentioning. The oddity is that if you build a lot of very small satellites, and each of them does a lot more than one big satellite, you don't need more launch capability, because a lot of those small satellites can be put in the same launch vehicle that you have.

So, in my view, the view is, not on the launch, but on the payload. So, what you can do for one kilogram of mass-to-orbit, what you can do for one kilowatt of electrical power in orbit.

MR. WEST: Okay, John, so we've heard Adam's vision, Antonio's vision. What's your vision?

MR. ROTH: I think the exciting thing about being in a new economy of space, commercial space, is, we're not exactly sure where it's going to end up. And it depends on what your values system is. Where's the big economic benefit -- or, for example, they're doing drug trials for Alzheimer's disease on the Space Station, in microgravity. And they're finding that the microgravity environment allows you to do the drug trials much faster, and find out which drugs have promise, and which drugs don't have promise.

So, if you think that the pharmaceutical companies that spend hundreds and hundreds of millions of dollars a year on research -- if they can cut that research time in half by being able to do research in microgravity environments, then there could be huge economic potential there.

As Antonio mentioned, satellites are exploding in what's going on -- the skyboxes, putting up full-motion video, satellites. Planet Earth is putting up planet spaces, putting up hundreds of satellites. So, the whole economy, in terms of Earth observation, is going to be changing, and that's going to have impacts on weather forecasting, and on environmentally monitoring the Earth, and seeing what pollution is doing to the Earth.

And there's so many different areas that the space economy could grow in -- and I think some of them are going to turn out to be incredibly high economic impact, and some of them are going to go bankrupt. But at this point, you don't know. It's like the beginning of the laptop computer age. You can say, "What's going to be the most interesting thing you can do with a laptop computer?"

Well, things that they'll do 10 years from now in space, we can't even envision what they're going to be doing. That's what I find so exciting.

MR. WEST: Okay. Why don't we move to the audience? We'd be happy to take questions.

We have a gentleman right here. There's a person with a microphone coming up behind you. If you could give us your name and your organization.

MR. WHITEHEAD: Sure. My name is Peter Whitehead. I'm an AAAS fellow at the National Science Foundation.

Thank you very much -- very, very interesting talk -- extremely interesting. And, unfortunately, I'm one of those people that has a two-part question; I apologize in advance.

The first part of the question is -- has to do with STEM education. My family's actually from the Eastern Shore of Virginia. Thank you for the shout-out. We appreciate that very much, and we're very happy about what's going on at Wallops Island.

I noticed that Mr. Harris, for example, got his education courtesy of the U.S. taxpayers.

MR. HARRIS: Correct.

MR. WHITEHEAD: And I'd like to hear the panel's point of view as to we can feed that pipeline to get the smart people, the innovation that we need into space technology.

And the second part of the question, which I'll do now, is, there was an article recently in *the New Yorker Magazine*, where I get all my scientific information. It spoke about the willingness, essentially, of the Chinese to very carefully and methodically steal our technology. It helps them, obviously, leapfrog us in many ways.

And I'd like to know how, if at all, you all are incorporating that into your business plan.

MR. WEST: Okay, STEM education and China. And he says they're taking intellectual property.

MR. ELIAS: Thanks for the kudos.

It used to be, back in the '70s, that space was such a unique bleeding-edge, state-of-the-art activity that the best and brightest of our graduates wanted to work in space.

Today, space has a lot of competition for the best and brightest. There is genetic engineering. There's bio-medics, electronics. I mean, there's all sorts of very interesting stuff. How does space attract the best and brightest? And even more importantly, how does space motivate the best and brightest to go towards STEM education and STEM activities?

Our main base is here in the Washington area. As a matter of fact, we are the largest manufacturing entity in Northern Virginia and the largest satellite factory east of the Mississippi. It's next to Dulles Airport.

But we have a lot of competition, especially from the -- with all due respect -- viewgraph factories that employ highly qualified people with security clearances. And they only have to work nine to five, and they pay much better than we do.

It's interesting to note that we lose a lot of our engineers and scientists to these viewgraph manufacturers. But because they offer them better compensation, easier working hours, you name it -- what's amazing is how many of them come back in about a year, 18 months because they suffer from what I call hard work withdrawal symptoms. That is, they're sick and tired of manufacturing viewgraphs; they want to go back and touch satellites and spacecraft.

Space has a unique combination of need for high intellectual content, such as astrodynamics, and very advanced structural mechanics, and state-of-the-art electronics -- while, at the same time, transforming that intellectual activity -- that basically STEM activity -- into hardware that you can touch, hardware that goes to orbit, hardware that does things. Very few activities have that unique combination.

You work for Apple. You design something wonderful, like the iPhone, and then it goes to China and Foxconn to be manufactured -- whereas, if you design a satellite or a spacecraft for Sierra Nevada, or for SpaceX, or for Orbital, you go down to the Cape, you launch it, you see it, you have butterflies in your stomach -- because, remember, space launch is the fastest way mankind has designed to destroy the most amount of value in the shortest amount of time, other than nuclear warfare.

And I think that is what's pretty unique about space -- what the space can use to motivate students.

Now let somebody else --

MR. WEST: Okay. STEM or the China --

MR. ROTH: Yeah, let me comment on the STEM. We're huge supporters of STEM education, and we have maybe a different experience than Antonio's got. We've been flooded with resumes. Students are so excited, especially about the new space -- the growth of new space. Everybody wants to work on Dream Chaser. Everybody wants to work at SpaceX.

We get resumes for internships, for permanent positions -- and a lot of these people are coming from some of those other industries that they thought would be fun. So, I think people working at Google are working at the place you'd think would be exciting. They see space, and they've always dreamed of being in space. And so we see an incredible excitement.

Our company's been funding a number of universities to support us. And the University of Maryland is one of them that I'm going to tomorrow, as a matter of fact. They have a Neutral Buoyancy Lab at the University of Maryland where they can simulate doing extravehicular activities. We've provided them a full-scale model of our Dream Chaser vehicle that they're putting into their Buoyancy Lab, and the students are doing experiments for what it would be like to do EVAs out of the Dream Chaser vehicle, with astronaut suits on.

And it's incredibly motivating for the students. You know, the outpouring of interest that they've gotten in that project -- we're in Colorado, in between Denver and Boulder. We've been funding the University of Colorado for work in our cockpit layout, and human factors, and what would the astronauts -- how should the astronauts be able to control the vehicle?

And there's three or four other universities that we have ongoing relationships with. So, we try to give back to the universities, get them excited about it, and, in return, we get incredible students that come out and want to work in our industry.

MR. HARRIS: Yeah, I'll mention -- at SpaceX, one of our HR goals, one of our hiring goals, is to hire about half of our new employees from universities -- so folks coming out of STEM education and things like that.

And what we find is, those young folks who are coming into the aerospace industry really do not want to be told, "You're going to work on a part that's been around for 30 years, and you're going to work on that for 12 years, and it might launch." What they want to work on is things that go to orbit. They want to see things work. They want to see their part get manufactured, and tested, and to be hands-on.

And so one of the things that we think could be very helpful from decision-makers, policymakers, and others in the area of STEM is to have more challenges. You know, there are these robotic challenges. There are rocketry challenges. There are a number of these -- even the vehicles-across-the-desert type challenges that go on from universities, sponsored by a science foundation, sponsored by NASA and others, that really give college students -- and even, sometimes, high school students -- hands-on engineering experience.

So, when we look at new employees at SpaceX, we hope they're not the viewgraph employees -- but we see that a lot in this industry. What we want is, folks who want to work on things, who want to tinker, who want to engineer, and who want to create new things. And so that's the best of engineering.

If you're an engineering student, you've spent four years sort of in all of your college classes, and it's time to get out and build something. And so we see a lot of the folks who are coming into our industry motivated by that -- that they want to come out, and they want to build something, or they want to see it on orbit, and they want to see it perform.

Your second question was -- help me with --

MR. WEST: China.

MR. HARRIS: Competing with China? What happens with China?

MR. WHITEHEAD: No, not at all. It's just -- got to get the mic --

for the concept of -- there's this 800-pound gorilla. And that is, there are other countries that want to leapfrog the technology, the STEM process, if you will, of bringing people up through the ranks, developing technology.

And so they're quite willing -- they gave an example in *the New Yorker* article of someone who had been in the United States for decades, and was delivering reams of material from Rockwell and Boeing.

And, again, that was just -- I didn't mean to be non-diplomatic.

MR. HARRIS: Sure.

MR. WHITEHEAD: But I'm picking on them specifically because they're in the news.

MR. HARRIS: Yeah. So, I don't have any expertise in the programs going on in China, except to say what I read is that they're spending a lot of money. They're spending a lot of resources. They're spending a lot of capital, and that they are going to continue to push the technology.

And so I guess, just from our perspective, we'd like both private commercial sector, civil sector on the NASA side, and the national security side in the United States to continue to do the same.

MR. WEST: Okay. Other questions?

Yeah, on the very back -- in the back row, there's a gentleman with a question.

MR. MARTEL: Hi. Thank you. My name's Alexander Martel, and I'm a law student at Georgetown. I've been studying space law, so I like to think I'm sort of STEM-adjacent.

But my question is about the legal environment that private space companies operate in. It's sort of been developing a lot over the last two decades, especially. I wonder, are there changes in the law or regulation that you'd like to see from Congress, from federal agencies, or even in how the U.N. regulates space through its space treaties?

MR. ROTH: Yeah, absolutely. Yes, the transitioning from this government model -- you know, NASA can pretty much do whatever they want to do when they launch things; same with the DoD. They're sort of outside the FAA regulations. They're outside all the regulations.

What we're finding as we balance that line between, yes, we're going to do some missions for NASA, and we're covered by NASA. They're NASA missions, so they're regulated by now. But now, anytime we do a mission that's not for NASA or not for the DoD, now it's a commercial space enterprise.

And nobody's really done this before in space. Nobody's carried private people into space, whether it's people that are tourists, or whether it's a commercial company, like a pharmaceutical company. So, all the laws about how space applies, generally, internationally, are government-to-government. You know, governments have responsibility for any missions launched out of their country. So, the U.S. government has responsibility if we, as a U.S. company, launch something into space.

But it's changing rapidly into, who has liability for the passengers that are on the space vehicles? Who has liability if we come out of orbit, and we, you know, happen to land not where we want to land, and we destroy some property? So, who has economic liability for that?

So, the insurance industry -- there's a lot going on there in trying to define, okay, how are insurance companies going to insure companies like ours? And what's our liability going to be? Can private individuals that are going to go into space sign waivers? And will those waivers hold in court? I mean, you can have somebody sign a waiver, and you don't know if it's going to be legally enforceable.

So, there's a whole number of issues that we struggle with every day in working with NASA, working with the FAA, working with the insurance industry, working with other regulators on how this is going to work.

Our vehicle's kind of unique. We can land at a commercial runway. We don't have to land at Kennedy. So, we announce that we signed an agreement with Houston. Houston is putting a spaceport in place, and we've signed an agreement to look at landing our vehicle from space in Houston. Well, how is that going to work? Our vehicle can be manned. It can be unmanned. It's not powered. It's a glider, like the shuttle, so you're coming in over populated territories in an unpowered vehicle.

There are so many issues related to how that's going to work that really need to get worked out here in the next few years. There's a huge need to focus on those issues.

I'm glad you brought that up. Thank you.

MR. WEST: Adam?

MR. HARRIS: Yeah, I'll say a very similar response -- that there's a tendency that we could overregulate. And a lot of this comes from analogy. When folks think about the legal regime in space, they usually analogize to the airline industry what type of regulations are put in place for airline passengers. I would hypothesize that we're just not there yet.

And the way I think about it is, the airline industry has a lot of regulations because of the way that industry has grown up. I would think of space flight and future human space flight more much like a sporting adventure-type thing. You know, it's crazy to say -- sort of bungee-jumping waivers that are caused by those that are doing this for entertainment, and fun, and excitement is a different regulatory regime.

And I guess I would say, we have to be careful not to overregulate before the industry even gets started, because I think we're at the cusp of that, and you have to allow some innovative ideas to occur.

MR. ELIAS: Let me once more go from the much farther ahead in the future viewpoint of my colleagues to something a bit more short-term.

A few years ago, the traditional International Traffic in Arms Regulations -- or ITAR -- were administered by one arm of the United States government, and then it was transferred to the State Department as a consequence of certain political events that happened a few years ago -- which had its origin in internal domestic U.S. politics. That caused things such as a communications satellite to be considered a weapon.

To those of us that export satellites outside the United States -- and my boss, Dave Thompson, the founder of Orbital is fond of saying that one satellite we sell to an outside customer offsets 25,000 televisions imported into the United States.

For us, ITAR is a marketing obstacle. That is, there are competitors from outside the United States that use the excuse of ITAR to sell so-called ITAR-free satellites. A transition out of this regime that had its historical origins in a domestic policy incident into something a little bit more rational -- for instance, administered by the Department of Commerce that has to outweigh political benefits with commercial and economic benefits would be a great improvement.

That transition is happening right now, and we just hope that the transition is effective, quick. What we want to do is to live in no man's land between state and commerce for months and months to go, being regulated by both, because one hasn't let go before the other has grasped it.

So, for us, the short-term need is to have a fast, effective transition from the old regime to the new regime.

MR. WEST: Okay, right here is a gentleman with a question. There's a microphone coming right behind you.

MR. MORRING: Thank you. I'm Frank Morring, with *Aviation Week*. And I have two questions, one for Adam and Antonio, and one separate for John.

In light of what Antonio's said about the future -- the near-term future of technology advancement, I wonder if you could discuss a little bit about, how do you see your work in reusable launching work? And if Antonio could comment on that, as well.

And then for John -- you've done work in suborbital engines with Virgin Galactic.

MR. ROTH: Mm-hmm.

MR. MORRING: I wonder if you could just -- I'm sure you've studied suborbital point-to-point delivery. I wonder if you could talk about that business a little bit, too.

MR. HARRIS: Yeah, sure. So, Antonio said he was going to disagree with me on the rocket business aspects -- and I actually agree with what he said. What he said was, with chemical propulsion, we've reached the limits of thrust and efficiency. ISP is what we use in our industry, and I think that's correct. With chemical rocket technology, we've figured out the best way to use those propellents to get to orbit.

But one of the areas that SpaceX is exploring, of course, is reusability. And so while the thrust and efficiency of the rocket engine is what it is, if we can get those engines back and reuse them, we think we can change some of the economics of the launch industry.

We're fond of saying, you know, if you took the plane flight from New York to Paris, and you threw away the plane at the end of that flight, that ride would be quite expensive -- probably $500 million for that ride. And yet we can buy tickets at the airlines and get across the ocean.

I don't think space flight is going to get to that point, but where we're starting is, SpaceX advertises our prices for a Falcon 9 at $60 million to get to orbit. If we can start reusing those rockets and those engines, say, 10 times or 100 times, we can change the economics -- because what happens in this industry is, as the prices of launch go up, then satellites add more -- and add more technology to the specific satellite that they're launching. And then the prices of those satellites go up.

And so we then do this thing called Mission Assurance, where we add a lot of cost to the satellite, which then the insurance industry and others come back to the launch folks and say, "Well, let's add a lot of cost to the launch side." And we get in this cycle where prices are going up, and causing what we have today in this industry, where we have few launches and few rides.

And so we think this reusable technology is something where, quite frankly -- and back to the gentleman's question about where China is going

-- you know, if the space transportation industry stagnated where it was today, SpaceX, and Orbital, and the U.S. companies would be competing with Aerion, and Proton, and the other companies.

Five to ten years from now, China is going to be competing very well with us. And they have a lot of resources backing that -- their industry.

And so one of the ways the U.S. can keep up is to start thinking about how we reuse rockets, and how we enable additional missions -- because I do actually agree that the technology advances are going to happen on the payloads. The electronics are better than they were 20, 30 years ago. We've seen that here in our daily lives.

And so the things that we can put on orbit are going to get better and better. And so I think reusability enables some of those missions. And Falcon 9, on its last mission -- for the time ever -- we essentially landed on the water. We did it over the water, because this is a very dangerous, dangerous job. We didn't want to do it near populated areas. But we came back to the water, we fired our engines, and we went to a zero velocity at zero altitude.

And so we essentially landed a rocket stage. We are going to continue to push that envelope, and get better and better to where we're eventually bringing those stages back to land -- and looking at what we get back. That will be a major advancement in this industry. Usually, you launch. You either lose the rocket in the ocean, or you lose the satellite to space, and you never see what happens to it when it's on orbit.

And so I think both this reusability concept with launch vehicles -- but, also, reusability, which is on the satellite side -- and so NASA is doing that with cargo transportation and crew transportation -- bringing those vehicles back, and seeing what has happened on orbit will advance the engineering that we're doing in our sector.

MR. WEST: Antonio, your view on reusable launches?

MR. ELIAS: Thank you, Darrell. You know how to bait people. My rebuttal to Adam has three parts.

First one, on the comparison with aircraft -- I think it's one of the weaknesses of our society that we compare space with aircraft.

Let me give you an example. When a Soyuz lifts off, carrying three cosmonauts or astronauts into orbit, it's producing, for a brief period of time, as much thermal power as 98 -- count them -- 98 Boeing 747s -- which carry a total of about 40,000 seats. So, you're essentially using the same amount of energy for three seats as you're using for 40,000 seats -- a factor of 12.

Interestingly enough, if you take an average transoceanic ticket price of -- I don't know -- $300, and multiply that by 12,000, you get the prices that the Russians are charging for a ride there.

So, there's a certain closeness of the argument that says, "Yeah, it makes sense, and it's energy." That's also why I disagree with my good friend, Joe, about whether a bunny hop, 200 kilometers altitude, is space flight -- like the 550 people who went to orbit. There's a factor of 36 difference in the energies involved.

So, now back to reusability. In 1972, there's a famous study that Princeton Econometrics did for NASA, where they were arguing about the economic benefits of reusability for a space shuttle. And it was concluded that the reusability of the space shuttle made sense if you were to flight between 15 and 16 missions a year.

The reason for that is that reusability does not come for free. When the SpaceX first stage has to come back for land, it is using a non-insignificant amount of its energy -- that is, its fuel -- to go back to *terra firma*. And if the stage one recovery goes to orbit, you are carrying, in addition to your payload, all the paraphernalia required to come back.

So, reusability does not come for free, and that is why you have to have, like, 50 to 60 missions a year to justify reusability; otherwise, expendability wins, hands-down.

Now interestingly enough, in 2002, we at Orbital performed a second study as part of a different study that NASA was sponsoring us for to recompute what the reusability magic number was. And guess what we got? Fifty to sixty a year. Now why is that, so many years apart, that we get the same result?

And it goes back to the fundamental laws of physics mentioned earlier. Specific impulse and structural mass fraction have not improved in any significant fashion in those intervening 30 years. So, that's why the answer today is the same one as it was in 1974.

In 1974, NASA said, "Wonderful. Perfect. We're going to fly the shuttle once a week," so 50 to 60 years is right on the sweet spot. What did reality do? Four and a half average flights per year -- worse than a factor of ten below what is required for reusability.

So, if the absolute elasticity of the meant-for-launch with price is sufficiently high -- and if SpaceX is able to go to 50 or 60 flights a year -- their efforts in reusability will pay off handsomely. But if it falls short of 50 to 60 a year, it's going to be wasted money.

MR. WEST: Okay, John, there's a question for you.

MR. ROTH: Darrell, am I safe here between these two guys?

MR. WEST: That's the reason we put you in the middle.

MR. ROTH: Quick answer to Frank's question -- yes. So, the suborbital point-to-point, we are very interested in, obviously. The economics are very different from orbital flight. On orbital flight, we're launching on an Atlas V launch vehicle -- or maybe, eventually, on a Falcon 9 -- huge cost of launch to get there. Suborbital, we'd be looking at some very different -- like an air launch-type capability.

So, the cost of the launch of the vehicle for suborbital point-to-point is a small fraction of what the cost of orbital launch is. Now we're never going to carry as many as an airline in a very fast, rapid suborbital point-to-point, but we found that there are companies that are out there that are very interested in starting up a business model that can carry a handful of people incredibly rapidly from point A to point B. So, we're involved in some studies with those folks right now.

MR. WEST: So, we're almost out of time. I have a quick question on government contracting. So, each of you, being private companies, have lots of experience with this. And, Adam, I know SpaceX has sued the federal government over lack of competitive bidding.

So, problems that you're seeing in the current process, and any changes you would like to make, if you were in a position to make them -- any of you?

MR. HARRIS: Yes. So, I would say I think it's not surprising that the companies that usually win FAR contracts continue to win those FAR contracts. They know how to work the acquisition system better than new entrants.

And so I think one of the things the government needs to think about is, what are the incentives? And so with this Cargo Supply Program, NASA has thought about those incentives. And one of the things they said was, "Let's do business in a fixed-price manner. Let's put the risk on the companies, and make them sign up to a price that they won't go over." And so fixed-price contracts incentivizes companies to get the job done.

Cost-plus is the other way the government does contracts. And basically what the government is incentivizing there is, let's do the technology, but let's not really care about what the cost is. The cost is going to be what it is, and the government will end up paying whatever that ends up being.

And so the only downside on a cost-plus contract if you're the Program Manager is, you continue to bill, you continue to raise the cost, up until the point where your program gets canceled. So, you -- that's your incentive. That's a bad incentive, we believe.

We think the incentive ought to be mission success. And so incentivizing for safety, reliability -- we think that can be done in this area through fixed-price contracting. And we've seen a number of areas in the government sort of take up this mantle, and try to figure out how to do this in a more -- we call it a commercial manner, but it really is a way that the government has done business in the past.

DARPA has done this successfully. We've seen models with Skunk Works building aircraft that have been done successfully. NASA has used the Space Act Agreement, and DoD calls them Other Transaction Authority.

But, essentially, what it is is, they're trying to focus on the mission at hand, versus on the FAR clauses, which a lot of viewgraph companies know how to do very well.

MR. WEST: John or Antonio, any -- your thoughts on government contracts?

MR. ROTH: Yeah, the one thing I would add to that -- and I agree with what Adam said here -- is, government contracting tends to be very much at arms-length -- and very different in how the NASA is now working as a partner. This government, this private, commercial, and government partnership idea works so much better.

We have folks full-time from NASA, sitting in our facility on the Commercial Crew Program. They come to every meeting. They review every drawing. They go through every decision process that we make. So, they know exactly what kind of product they're going to get -- whereas traditional government contracting -- very hands-off. You're limited in what dialogue you can have with your customer.

They try to do everything through written requirements. And if you were trying to get your house painted, and tried to work with your painters that way, you'd never get a job done that you'd like. And that's what happens frequently, I think, in government contracting.

MR. WEST: Okay, Antonio, we'll give you the last word on this.

MR. ELIAS: Thanks. I don't think the real question is whether it's FAR or non-FAR contracting. After all, your largest contract is a FAR contract.

MR. HARRIS: Sure, certainly.

MR. ELIAS: I don't think it's either firm, fixed price or cost-reimbursable. I think each case is a separate one. I think the key recipe is competition -- let me add, enduring competition -- because any form of noncompetitive procurement requires the procurer -- whether it be United States government or myself, as a home owner -- to very actively specify and know what you want to specify -- whether it's firm-fixed price -- in which case, you say, "Oh, you wanted tires with that car? You didn't say that" -- or cost-plus, which is, "Oh, the tires are an extra."

In either case, it is the burden of the buyer -- *caveat emptor* -- to ensure the behavior of the producer.

In the opposite case -- in a competitive situation -- the buyer can, in a certain way, stand back, and let each of the two competitors essentially be the oversight or the policemen to ensure the behavior of the other one, because they know that if they're not -- don't provide the customer with a product they really need or the price that is competitive, then business will go to the other one.

So, my opinion is, enduring competition is far more important than the form of contracting.

MR. WEST: Okay, thank you very much. We're going to move right into our next panel, but I want to thank Antonio, John, and Adam for sharing your views. It's very stimulating and very helpful. Thank you very much.

MR. HARRIS: Thank you.

MR. WEST: So, I'd like to ask Michael and Nadine to come in -- come up.

So, consider the first panel just the warmup act for the scientists. And I have to say that Michael and Nadine have to have what I would consider to be the coolest jobs in the world, because they get to discover the new stuff that is happening, in terms of Mars, the Moon, the solar system, and way beyond. And they're just -- when you look at just for the last 10 to 15 years, we've seen amazing and new discoveries take place.

So, I want to introduce, first, Michael Meyer. He is the lead scientist on the Mars Exploration Program of NASA. In that capacity, he's responsible for the science content of current and future Mars missions. He also is the Program Scientist for the Mars Science Laboratory and the Curiosity Rover Mission. He was a Senior Scientist for Astrobiology and Program Scientist for the 2001 Mars Odyssey.

The Astrobiology Program was started in 1997 with him as a discipline scientist. So, he's been very interested in the study of life in the universe.

Nadine Barlow is Professor of Physics and Astronomy at Northern Arizona University. There, she serves as Associate Department Chair. My condolences on that position; I've been a Department Chair. It's a very tough job -- but, also, Director of the Northern Arizona University and NASA Space Grant Program, and Associate Director of the Arizona Space Grant Consortium.

Her research interests include the evolution of the cratering record through the solar system, the geologic evolution of solid surface planets, and determining the distribution of subsurface water reservoirs on Mars, Mercury, and the Moon. She's a member of the Mars Exploration Program Analysis Group. She's the author of a book, entitled *Mars: An Introduction to Its Interior Surface and Atmosphere*, which was published by Cambridge University Press in 2008.

But the most interesting thing I found in looking at her bio is, she actually has an asteroid named after her, in honor of her contributions to planetary science. This is asteroid 15466. Now when I first heard about this, I was worried, well, you know, what happens if this turns out to be a killer asteroid? Like, you know, you wouldn't want this to be your final legacy. She reassured me, there's no threat from this particular asteroid. So, I think we're okay on that end.

But I want to start with Michael. So, you focus on Mars, and, you know, there've been amazing discoveries there. So, we have kind of a non-science audience here. Could you just give us some of the brief highlights of what we've learned there, and why is this relevant for earthlings?

DR. MEYER: Well, it's been spectacular in our Mars exploration -- considering the way it started, with thinking Mars was very interesting and a potential habitat for life. Sending the Vike in there in '76 -- and, essentially, Viking's overall conclusion was, Mars was cold, dry, dead. And, essentially, Mars exploration, for quite a while, went in a moribund state, until it kind of got revived with understanding of life here on this planet, where we're finding life in all sorts of extreme places -- that we consider extreme. And it kind of pointed to, well, maybe we didn't look at Mars in the right way.

With that kind of lead-in -- revitalized the Mars Program, started a program of exploration in which we approached the planet as a planet, to understand whether or not globally it has the right characteristics for something that could've supported life at one point in time -- or even today -- and start looking at regional areas, and, basically, get more and more specific about, what do we really know about the planet? Because you can't understand life unless you understand the environment in which you're looking.

And so that has really been a revelation to planetary scientists, in general, of how we should approach looking at the planet. And it's just been fantastic the way the program has gone.

And, you know, speaking when it's a program of scientists on Curiosity -- we went there, we identified places that looked like they could have supported life. We sent a mission to one of them. We have all the right tools. We went through competition for selecting the tools that go to Mars, and, essentially, we've already met our prime mission objective in identifying a place on Mars that we are pretty sure could have supported life at one point in time.

And so the whole thing of looking at a sister planet -- whether or not life could've started there -- and getting a good handle on that -- is quite a spectacular finding. And one of the things I find most intriguing about it is, we look at life here on this planet. It started early on. We're not quite sure when. We're actually not quite sure where, other than, yes, we have life on this planet.

But early on, life started here as the same time that, when we look at Mars, it had the right environment, it could've supported life. Life could've started there. So, what happened? Did it, or did it not?

Well, one of the answers -- even if it didn't, it has a record of what was going on in the solar system when life started. So, oddly enough, one of the things that we can learn from Mars exploration is actually how life got started on Earth.

MR. WEST: Okay. Nadine -- so we've seen exciting new discoveries in terms of Mars's exo-planet. We're talking earlier about -- we seem to be finding evidence of water in a lot of different places. So, what are you focusing on, and what are you finding that you think is interesting?

DR. BARLOW: As you said, Darrell, I think a lot of it has to do with the fact that, over the past 10 years, we've started to realize that water is very abundant -- both in our solar system, as well as elsewhere. As Michael said, we've actually gone to Mars. We've identified habitable environments there. We definitely see that water existed on Mars in the distant past. It is there today, except that it's in ice form or buried underground.

And so one of the big questions that we have related to Mars is, how come it looks like it was probably very Earth-like early on? And what happened to it so that it actually has become the dry, desiccated world that we actually see today? Could something like that happen to Earth? Could we prevent that from happening here on Earth?

So, by studying Mars, by studying where the water resources actually are, it tells us more about the evolution of these types of planets and how the Earth ties into all of that.

But in addition to finding water on Mars -- and it's the standard joke in the community, how many times do we discover water on Mars and say, "We've discovered water on Mars"? But in addition to really identifying that, yes, there are areas on Mars where there was acidic water, where there was much more, you know, nice water that we could actually utilize.

The other thing that I find very interesting in the last 10 years is just identifying the vast regions throughout the solar system where we do actually find water. Now back in 1979, the Voyager spacecraft flew by the Jupiter system, looked at one of its moons called Europa, and we discovered that the surface of Europa was composed of ice, and it was very broken up. It looks very,

very much like when the Arctic is breaking up in the spring, and the ice is moving around on the oceans.

So, we came to the conclusion that Europa actually has a liquid water ocean underneath that ice crust. But in the last 10 years, not only have we confirmed that, yes, that is actually the case with Europa, just a few weeks ago, it was reported that they actually have identified plumes of water ice coming out from geysers on Europa.

But it turns out that one of Saturn's moons, Enceladus, also has these ice geysers. And just a few weeks ago, we started looking at the gravity data, and started to realize that, yes, there are indications that there is at least a regional subsurface ocean on Enceladus, as well.

Similarly for Titan, Saturn's largest moon -- turns out that features on the surface of Titan don't stay in the same spot. It looks like the entire crust is actually moving on some sort of liquid ocean underneath.

So, it's just amazing how we're finding that, more and more, there's actually water resources all around. And, as Michael said, you know, one of the big things for identifying that there has been water on Mars is the idea that, okay, it could've been habitable, you know, and we'd have those questions for these other bodies, as well. Are there life forms actually floating around in the oceans of Europa or Enceladus?

It's enough of a concern that when the Galileo Mission ended its time at the Jupiter system a few years back, it was actually directed to go into the clouds of Jupiter, and be destroyed that way, because there was a miniscule chance that, if the spacecraft remained orbiting in the system, that it might actually crash into Europa, and it might contaminate it.

So, that's one of our big issues, is, how do we prevent contamination of terrestrial microbes into these alien environments?

And it turns out that it's probably not just our solar system that actually has a lot of water and a lot of interesting places. One of the big results from the Kepler Mission is that planets seem to be the rule, as opposed to the exception, throughout our universe. We're finding lots and lots of evidence of planets around other stars. Kepler alone identified over 3,500 candidate planets around other stars.

And what we're finding is that these guys come in all different sizes, all different locations from their parent star. We're starting to identifying atmospheres around these guys -- some of which are very bizarre, like, you know, vaporous iron in the atmospheres. Other places, there's water vapor.

So, we're getting a much better understanding, in terms of planet formation and planet evolution within the last 10 years.

MR. WEST: Great. Thank you.

What do each of you see as the top priorities, in terms of future scientific exploration? Like, if you were the tsar, and could kind of dictate what our priorities should be, in terms of Mars, worrying about asteroids, kind of focusing on the exo-planets -- like, where should we be putting our money?

DR. MEYER: Wow.

DR. BARLOW: You go first.

DR. MEYER: Yeah. And in all honesty, I think it's more of a question of kind of, when are we going to put money on particular targets?

And as an example, Mars exploration has gone through a tremendous amount of opportunity, in terms of exploring the planet, and we're now at the verge of, in 2020, sending a mission that we will definitely send to a place that looks like it could've been habitable. It's going to have the right instruments. We're in competition right now for selecting those instruments.

It's going to catch samples. And this will be the first opportunity to have something on Mars that we may want to bring back. And it's kind of the first opportunity to actually get a sample from another planet that we selected, as opposed to an impacter sending our way.

And that really does set the stage of Mars being a very well-characterized planet. And, also, one of the things that we look at in the future is not only deciding whether or not life ever got started there, but, in all honesty, I think it's the only place in our solar system that has any real possibility of colonization.

And so, in the long term, I think going to Mars will be a theme -- whether or not we're doing it robotically, or whether or not we're doing it with humans -- because, eventually, whenever we're going to get off of this rock, the next rock is going to be Mars. So, that's one priority.

The other priority, as Nadine mentioned, you know, finding water everywhere. There are different ways to, you know, cut the pie, so to speak, in that we see moons around other planets that have water, that have the potential for life. And it's one of those things that we should go and look there, because depending upon what we find on Mars, what we find on Europa, what we find on Enceladus, it may give us very good clues as to what was going on in the early solar system, and where the places are that life could've began.

MR. WEST: Nadine, your view of future priorities?

DR. BARLOW: I would have to, you know, say ditto to everything that Mike said. I think Mars is really our goal. Again, as Mike said, I think it's a case where this is the most logical place, where we're going to find a lot of the answers to early solar system evolution that are actually lost here on the Earth, because of our very active geologic environment. I think it's going to hold a lot of clues, in terms of the conditions under which life can actually exist.

If we find that Mars has never supported life, it's going to be a big discovery, actually, because a lot of the necessary ingredients that we think are necessary for life, we're now seeing actually were there on Mars. So, if life did not get going on Mars but it did here on the Earth, why is that?

And, similarly, yes, going to the other objects that have the subsurface oceans, trying to understand whether or not they actually have life, the conditions under which life could actually exist -- those are going to be big things.

But I think a lot of it, too, is our continued exploration and our understanding, learning about places we haven't been to yet. Within the next year, we're -- as far as I'm concerned, 2015's going to be the year of the dwarf planets, because we have two missions out there. One is on its way to Ceres, which is the largest asteroid in the asteroid planet -- but also known as a dwarf planet. It's a very primitive body from what we can tell from Earth-based observations.

And yet, we now actually have identified evidence that water has interacted with the minerals on the surface. Now the question is, is that from inside Ceres itself? Is that coming in from comets? What's actually going on?

But, again, I think it's going to hold some very important clues to us, in terms of very primitive bodies, and how they actually evolve into what we see here.

The second big mission is, of course, the New Frontiers Mission, which gets to Pluto next year. And I'm from Flagstaff, where Pluto was discovered, so we still call it a planet. But it is officially a dwarf planet. And, you know, it's going to be a very exciting place to actually visit. It'll be the first time we've seen a close-up view of Pluto.

And our past experience with space exploration is that you have these ideas in mind when the spacecraft gets there, and by the time it leaves, everything has changed. And so I think, you know, just exploring more of these worlds that we have not really explored in as much detail as we have, for example, with Mars or the Moon, is going to lead to some very exciting new discoveries.

MR. WEST: So, each of you focused on different aspects of figuring out the origins of life and how it developed. What about the flip side -- the destruction of life? Because some people have said, you know, we need to be paying a lot more attention to the asteroids, because we already have the example of the dinosaurs. These objects, they could threaten the entire world.

How do you balance, like, Mars and some of the other explorations versus figuring out how asteroids operate -- either one of you?

DR. BARLOW: I can take that, since I study impact cratering for a living.

There, again, I think one of the really important new discoveries that has come out in the last 10 years is the fact that, with all of our armada of spacecraft orbiting Mars -- and now we've had them in orbit, at least off and on, for over 40 years -- is that we actually have discovered the formation of new impact craters.

We're actually seeing very small craters actually forming on Mars at a relatively rapid rate. We're starting to pick those up for the Moon, as well, and it's giving us a much better understanding, in terms of, what is the actual cratering rate? What is the impact hazard to our own Earth?

Now, granted, the Earth has a little bit thicker atmosphere than Mars does or the Moon does, so that helps to shield us a little bit. But as the events last winter in Russia, with the Chelyabinsk Bolide that exploded over Russia and caused a lot of damage -- that shows us that these things still happen.

And by gaining a better understanding, in terms of what the cratering rate really is and what the hazard really is, will help us better prepare, and decide what we have to do, if we do actually find an asteroid on a collision course with the Earth.

DR. MEYER: Well, I have to agree with Nadine that, you know, an asteroid is a real hazard. But if you're asking me the question, I think the biggest hazard to us is ourselves. And it's interesting coming from my astrobiology perspective -- and, okay, looking at the number of suns out there, stars out there, looking at the number of planets -- which is, you know, well over 1,700 confirmed -- just spectacular -- well, where are the aliens? You know, if life is out there in the universe, where are they? This is the Fermi paradox. Where are they?

So, Frank Drake has a great equation that has all the parameters of, you know, okay, what's the likelihood of a technological civilization happening on some other world? And one of the big factors is the survival of the advanced civilization. And so we are at that point of being advanced enough that we can wipe ourselves out. And so I actually think that's the biggest threat to us.

MR. WEST: Okay. So, on the last panel, we heard a lot of discussion about public-private partnerships. And certainly on the science side, like NASA long has worked with universities -- I'm just curious, from each of your standpoints, how you see kind of the university role evolving over time, and, kind of more generally, are there private companies that are starting to become active in the scientific part of the space program? I mean, how do you see these things working out on the science side?

DR. MEYER: That's definitely an interesting question. And I'm sure Nadine has a different perspective, because mine is relatively naïve.

And looking at the universities -- they're at an interesting point in time, where now you take courses online. How important that is versus being in-person for instruction, that sort of thing -- I think there's a real value to it, but how well that fits in with economics -- so I can see that universities have a real challenge of how they're going to transition in the next decade or so, in terms of, what do you do for students? How do you structure it? How do you make education not so wildly expensive -- is a difficult challenge.

On research itself, it's interesting -- the commercial world, there are lots of money things put into research. The kind of downside is that there has to be a payoff. You know, so when the, you know, Board of Directors says, "Okay, did you make any money from this research?" you have to have a relatively short turnaround time. And a lot of research that's done -- we have -- not only is your timeframe, "Oh, I'm going to make a great discovery in two years," it's kind of like you're not even sure if you're barking up the right tree.

And so in some ways, I find that government has a very important role to play in which they can fund many different trees for you to bark up, and then just big surprises -- the ones that you never expected -- have that opportunity to grow.

And so I think there will always be this public-private partnership, in terms of at least for research, just because you can't know what the really great things that are going to happen without having a much more diverse funding portfolio.

MR. WEST: Nadine?

DR. BARLOW: Yeah, the universities are definitely going through challenging times -- we'll put it that way. Certainly, at my institution -- Northern Arizona University in Flagstaff -- we've grown dramatically over the last decade. And we're bursting at the seams, in terms of trying to find places to put all those students.

There is this effort to go to more online courses, but what we've discovered -- especially in the sciences -- is that online courses really don't take the place of the in-person interaction. And we see that especially with hands-on labs -- and just even the research experiences.

One of the things that I have noticed that has really grown over the years -- in the years that I've been teaching -- is the big emphasis on research opportunities for both the undergraduate and the graduate students -- and especially at the undergraduate level. The number of opportunities have blossomed dramatically, and it really has helped us to retain a lot of our students -- and to convert them into the STEM fields. We were talking earlier about getting more students involved in STEM.

Getting that hands-on experience, applying your classroom knowledge to an actual research problem, that's key to actually getting these students excited, getting them involved, and keeping them in the actual fields.

And so I would expect that a lot more of these opportunities will present themselves. That, I think, is one place where perhaps private industry can also help -- is by providing more funding to these types of opportunities, so that the students can get those experiences, and then the private industries can go ahead and actually capitalize on that by hiring on some of these students.

In terms of international, certainly, space exploration is not just the realm of the U.S. or Russia anymore. A lot of different countries are out there, and, of course, there's a lot of interaction between the different countries. The U.S. has instruments on, for example, the European Space Agency's Mars Express Mission -- and vice versa.

So, there is a lot of cooperation and a lot of interaction. And as we move to bigger and bigger missions, to try and explore more detailed information about these bodies, I think the international collaborations are going to become even more important.

DR. MEYER: Yeah, Nadine reminded me of something. And that is, you know, having genuine experience -- the opportunity to actually participate in some research and that sort of thing. And so there's been a whole, you know, movement for citizen science and that activity.

And I know, for me, sometimes, it's hard to grapple with, you know, how do you actually make that, and make it real?

But there are some examples where it's been very beneficial in having -- you know, NASA, I think, has done a great job in going out of the way in trying to include the public in exploration.

So, a good example on Curiosity -- all the images are taken. They’re online within 24 hours of after being taken. It's usually almost instantaneously -- so that everybody can see what the scientists are saying and trying to explore.

A good example is there's a thing called Mars Student Imaging Project. And this gives the opportunity for students to look at pictures of Mars, decide what they think is interesting. What do they want images of? And then they can ask the satellite -- they can ask Odyssey to take an image of something they're particularly interested in, and then they do some real research on it of, what does this mean? What did they find? Is that really a crater?

And it's amazingly invigorating for the students to -- they get the opportunity to deploy a spacecraft, do science -- and it's real science. You know, there are publications of the student finding, like, a lava tube opening -- going to professional meetings and saying, "Here's my research. This is what I found."

And I find that one of the kind of changes in what we're looking at today -- because of the internet, because we are able to bring everybody along with us, individuals, no matter where they are -- or, you know, groups of students, no matter where they are -- can have an opportunity to participate in something a little bit larger than life as part of their education.

MR. WEST: Okay, great. Let's open the floor to questions from the audience.

So, over here on the aisle, we have two questions. We'll take each of you in turn. There's a microphone coming up from behind. So, if you can give us your name and your organization.

MR. HESTER: Thank you. My name is Zach Hester. I'm a student at George Washington University's Space Policy Institute.

And sort of going off the earlier question about priorities -- what about priorities for science here on Earth, particularly around marine biology, oceanography, that might be applicable to our search for life in outer space?

So, I know NASA does some applied science programs in which they work with NOAA and other agencies. But what sort of science would you like to see done here on Earth that would be helpful in terms of our search for life?

DR. MEYER: It's an interesting question for a couple of reasons. One is, my background is oceanography -- and so it's in the process of learning about the oceans, and how, basically, the ocean is one ocean, and we're in one world -- kind of helped me set the stage for looking at extreme environments and -- which ended up bringing me to being in -- basically, doing NASA research.

What are the key areas? Well, one -- that, I'm not really positive, because I haven't been that much into the research today. Certainly, one of the things that helped set the stage for why we should go back to Mars and reconsider whether or not there's any potential for life was, in fact, finding hydrothermal vents in, what, 1976.

The same time the Viking landed on Mars, all of a sudden, we find life in a place that we never expected to find it. And that kind of opened up the whole world of, you know, looking at life in extreme environments. And it's trying to understand not just where life is at room temperature, but what the extremes are.

So, the ocean itself -- I mean, this is a tremendously challenging problem in that we're at an age where we've gotten to the point where now, we're starting to overfish in many of our fisheries, you know. And we're starting to challenge the sustainability of many of the fisheries that we have.

And I think some of the research can go into that, and how to best approach it so that, as our populations grow, we figure out how to have the ocean be on a sustainable basis, instead of exploiting some new part of the ocean that we haven't tried before, and kind of fishing that out.

So, I see it as a challenge, in that our capabilities of using the ocean is beyond the ocean's capability of sustaining itself. And so, in some ways, we have to figure out how to manage that on a global basis, because now we can fish outside our own borders.

MR. WEST: Nadine, do you have a --

DR. BARLOW: I think another aspect of the oceans is that the oceans really tie in very closely with climate here on the Earth. And, of course, we all have heard of El Nino -- especially those of us in the Southwest. We know that El Nino's kicking in. Next year, we might actually get some rain and some snow, unlike this year. But the very close tie between the ocean and the atmosphere, I think, is key.

And one of the interesting aspects of how that ties in with space exploration is, we go to these other planets; we look at their atmospheres. They're not nearly as complicated, in many respects, because they don't have those liquid water ocean atmosphere-type interactions. But yet, we can go to bodies that are completely composed of atmospheres -- like, Jupiter, Saturn, Uranus, and Neptune. We find that, even there, the atmospheric dynamics are very, very complex.

And so by gaining a better understanding of kind of pure atmospheric dynamics in these purely atmospheric worlds, we can bring that knowledge back to the Earth, and start to enhance what we already understand in how the oceans actually go ahead and affect the atmospheric dynamics that we see elsewhere.

MR. WEST: Okay, there's a question right behind -- right there.

MR. MARTEL: Thank you. I'm Alexander Martel, and I'm a law student at Georgetown University.

My question is about sort of the intersection of science and politics -- and particularly about the Constellation Program of the last decade and NASA's current plan for Mars.

My understanding is, the Constellation -- the idea was, we would go back to the Moon first, and then we would proceed again to Mars. And that was under President Bush, and President Obama canceled that. And then there was an outcry, and so the intermediaries said, "Okay, well, we'll go to an asteroid."

And I think, to a lot of people, that seemed like a change driven by politics -- it couldn't be the same thing chosen by the last administration.

So, my question is about -- are there actual, you know, particular scientific benefits to lassoing an asteroid to bring you to the Moon, visiting that first, and going to Mars -- rather than the Constellation Plan?

And then, if you would like, to comment more broadly about how you deal with political influences on scientific exploration.

MR. WEST: Great question there, yeah.

DR. MEYER: Wow.

DR. BARLOW: It's, like, one for Mike.

DR. MEYER: I actually have two answers to it. One is, I mean, the benefit of going -- one, we should go to Mars. You know, do the science. Send humans. It's our -- not our next abode, but another abode. I want to make sure we still keep Earth viable and happening.

So, one of the advantages of going to an asteroid is that you don't fall into a huge gravity well. The problem with going to the Moon is, when you land on it, you need the resources to get off. And so that costs you.

And, in fact, I found it very interesting to listen to the earlier panel of the real costs of getting off this planet, into space -- is basically costs of fuel, with minor things thrown in.

So, that's one of the real drivers why we might want to go to an asteroid instead of the Moon as your launchpad to go on to Mars.

The whole politics things -- I got to Washington a while ago, and I realized that, you know, these guys are really good at this whole policy stuff. I better not even tread in those waters.

What I'm going to do is, I'm going to tell them what the good science is, what we ought to be doing, what the questions are. And even if it's impolitic at the time, eventually that good question will be recognized as a good question, and we'll get to do it.

And, in all honestly, that's how, I think, astrobiology grew into a very major discipline in and of itself, and why we've been able to continue the exploration of Mars -- because focus on what the questions are, why you want to answer them, and then make available the tools to actually go and do it.

DR. BARLOW: Yeah, I agree that, you know, we really need to have the science driven by the science questions. And, you know, every administration, as you point out, they tend to come up with their own plans. And what should be the goal of my administration? And then the next administration comes in, and it seems to be a little bit different.

But I think in the end, what really does drive what we do are the science questions. I think every administration comes down to, yes, you know, once you make your arguments about, why is the Moon a good place? Why is Mars a good place? Why would an asteroid be a good place to go? Those are the types of arguments that we use in the scientific community to actually make our decisions, in terms of, what should be our 10-year plan in terms of space exploration?

And once the scientists come up with their 10-year plan -- what's known as a decadal survey -- then that goes to the policymakers, and we make our arguments. And then that's how policy becomes set.

So, you know, while politicians can put out these grand plans, I think, in the end, it's the science that actually drives where we actually do end up going.

MR. WEST: There's a question right there, young lady.

MS. JONES: Hi. I'm Therese Jones. I'm at RAND.

Going back to the creation versus destruction question, I think a really important component of that question is the fact that there are really two separate pots of money going into asteroid research, in particular. One is more on the astronomy side, where we're interested in the origins of the solar system. But a lot of astronomy programs now have a very large defense component. And the U.S. Air Force monitors near-Earth objects.

So, I guess my question is, it seems like we have to justify astronomy programs more and more by utilizing some portion of them for defense purposes, especially with NASA's funding going down. So, I was wondering what sort of pressure you see to tie astronomy programs into defense.

DR. BARLOW: I think it's a very close tie, as you point out. It's a case where, by doing our scientific studies of asteroids, particularly the spacecraft missions to asteroids, where we can actually get an idea in terms of, you know, what are the sizes of these objects? What are they composed of?

One of the big things is, are asteroids solid bodies, or are they what we call rubble piles, where they're just a whole bunch of small pieces kind of held together by gravity? If you find an asteroid that's on a collision course with the Earth, and you want to divert that asteroid out of that collision course, you need to know whether you're going to be pushing on a piece of solid rock, or if you're going to be pushing on a bunch of smaller pieces that are just going to kind of disperse.

So, the scientific exploration of the asteroids is necessary, in order to understand, what are the capabilities that we're going to need, in order to divert an asteroid that could potentially be hazardous to us?

So, I think they're tied together very, very closely.

MR. WEST: And if I could just quickly follow up on that -- what is the relationship between NASA and DoD, in terms of -- I mean, DoD is launching things in their satellites. How do they function together?

DR. MEYER: We sometimes know what they're doing.

MR. WEST: That's actually a pretty good answer to that question. So, there's not a lot of close coordination, it sounds like.

DR. MEYER: On some things, there are, because you have -- not necessarily -- you don't have the same goals, but you have the same opportunity. So, you know, it's kind of like upper atmosphere flights, where you're interested in what's going on in the chemical makeup of the atmosphere or that sort of thing, while they're interested in flying over and spying on different countries. You can make use of the same U2 flight to collect information that is useful for the science.

But we don't have the same purpose, and so, many times, you don't have the same opportunity.

MR. WEST: Okay.

DR. BARLOW: Certainly, a good example of that was the Clementine Mission to the Moon. And the Clementine Mission was actually a Department of Defense mission, which was designed to test the (inaudible) of Star Wars technology.

But it turns out they had, I guess, extra space on board. And NASA said, "Can we go ahead and put some cameras and instruments on board?" And they said sure. So, we got some good scientific information from that mission, even though it was a military mission, and most of us didn't know most of what it was actually doing.

MR. WEST: Okay, we have two questions up front. Beth has a question from our webcast leadership, and then we'll go to this gentleman here.

BETH: Hi. So, I'm asking this question as a proxy for Rebecca Carroll, who is an Editor and Reporter at Nextgov. She's asked this over Twitter:

Do government and private sector priorities in space align? And, perhaps, I think, more interestingly or importantly, are there areas where they're at odds -- which builds on what you were just talking about.

DR. MEYER: So, right now, they are aligned, because we're kind of focusing on what the same opportunities are. And, I imagine, as the private sector matures, and they develop a commercial base for much of what they want to do, there may be some divergence.

And I can imagine -- let's say in the longer term, one of the issues that may come to the floor is interplanetary protection, you know.

So, imagine, you know, 50 years from now, SpaceX can send tourists to Mars, while we may have a problem with the idea that if Mars is a -- has Martian life, we don't really want to send humans there, and accidentally wipe out the Martian life. That would be, you know, too bad -- or actually have the humans come back carrying Martian life, which could threaten life here on this planet.

So, I can imagine, as we go forward, and you start talking about exploring specific areas where there may be a conflict where general public good is, perhaps, a jeopardy to a single private contractor.

DR. BARLOW: And, certainly, I think, also, there will be -- you know, especially future opportunities for private and government, you know, exploration -- because, of course, our space program today is going ahead and identifying where resources are located on places like the Moon, and asteroids, and Mars.

And a lot of the private companies in the future will probably be interested in actually mining some of those resources. And so there will need to be that interaction between them, to utilize the information that we're gathering now in identifying where the best places would be for these people to go ahead and actually do their mining.

MR. WEST: This gentleman right here has a question.

MR. PUTIC: My name is George Putic. I'm with Voice of America.

You are mostly talking about exploration of Mars, asteroids, Saturn, moons. What about our own Moon? Have we lost interest, or do we feel that we know enough?

DR. BARLOW: Definitely not. There certainly is no lack of interest in the Moon. As I mentioned, there is now a very large international component, in terms of space exploration. And much of that has actually been focused on the Moon in the last few years.

So, not only has U.S. returned to the Moon with the Lunar Orbiter Mission, and the GRAIL Mission, and Lottie, and all of those missions, but we also have had India sending a mission to the Moon -- which, actually, was the one that helped to identify evidence that there's, you know, hydroxyl or water in the lunar regolith -- or the soil of the Moon.

We also have had, of course, China being very involved. They recently landed a robotic rover on the surface of the Moon, and are busy exploring there. The European Space Agency had a mission to the Moon not too long ago.

So, it's become a very international type of exploration of the Moon in recent years. And there is a huge amount of information we still don't understand about the Moon. And these missions are actually showing us how little we really did understand, even after sending the Apollo astronauts and the lunar missions, actually, there in the 1960s.

We came back with a certain understanding of what, you know, the Moon was, how it formed, and now a lot of the new results are actually showing us that we're going to have to reevaluate what we thought was actually going on, because things are not quite that simple.

MR. WEST: Back there, on the aisle.

MR. JONES: Yes, hello -- Creighton Jones, with *21st Century Science and Technology*.

Actually, a follow-up on what you were just discussing regarding the Moon -- there were a number of statements from top Chinese officials after their recent soft landing that their long-vision intention is for the industrialization and development of the Moon -- rare Earth minerals. And, also, they specifically referenced the mining of helium-3 for potential third-generation fusion reactors.

So, my question, number one, is, how feasible do you think the Chinese plan is right now? Is -- you know, do you think they're on pace? Are they literally on -- are they actually on the pace they said that they are on, in your assessment, number one?

And number two, in reference to the Moon, were budgets not an issue -- which is a big, you know, hypothetical -- do you think NASA would still be pursuing an aggressive approach to the Moon?

MR. WEST: Do either of you feel like this is in your area of expertise?

DR. MEYER: Well, I mean --

MR. WEST: It's a great question, but --

DR. MEYER: Yeah, it is outside my area of expertise by a long shot, but, you know, it is one of those things -- they have the resource, and they're spending money. They've gone a long way. They have soft-landed a rover on the Moon. So, whatever the projection is, in terms of industrializing the Moon, I have no idea. I didn't read the article -- what the timeline is.

But, certainly, between now and sometime in the future, that's a very real possibility, yeah. How long that takes, I have no idea.

DR. BARLOW: There, again, China's not the only country. I know there was an article recently about Russia, saying they wanted to colonize the Moon by 2030. And, you know, that's only 16 years away. That might be a little bit of a stretch.

And we all know from, you know, working in the space program, that, a lot of times, you get sidetracked a little bit because of failures, or lack of funding, or what have you. That may be someplace where private companies can help out, you know, and help to support some of these types of missions.

But China has really been pushing ahead the last few years with their space exploration program. They've now had astronauts, you know, orbiting the Earth. They've landed the rover on the surface of the Moon. So, they're certainly pushing ahead. They're very interested. They're putting the necessary resources into the exploration.

Whether or not they'll actually reach their goal of exactly when they want to start the industrialization, that depends on what happens in the meantime. But I certainly think that they're on that trajectory where they certainly could do it.

MR. WEST: So, I have a question. Each of you know kind of what's in the pipeline, in terms of, what are the missions that we're planning -- and kind of the questions we're interested in exploring.

So, 25 years from now, what is your best guess on -- what are we going to know then that we don't know now, that people will think, "Wow, that's amazing"?

DR. BARLOW: Hopefully, by then, maybe we will have actually identified if there's life anywhere else in the solar system. And that would be a real key discovery. And I think within the next 25 years, if we continue our focus on space exploration of Mars and some of these other icy worlds in the outer solar system, we'll have gone a long way towards being able to answer that question of whether or not life has ever existed on these other worlds -- or exists there today.

MR. WEST: And if we discover that there are multiple places of life just within our solar system, what are our conclusions in terms of the rest of the universe, given the trillions and trillions of stars that are out there?

DR. BARLOW: As they said in the movie *Contact*, "If there's no life out there, it's an awful waste of good space."

MR. WEST: Michael?

DR. MEYER: And, you know, as a lead-in, that does point to, you know, if it's actually easy to create life -- if we find other places in our own solar system, then it just, you know, super populates our universe with other civilizations, that sort of thing.

So, on the question of, in the next 25 years, what do we think we might find out that we don't know now -- by then, I think we actually should be able to figure out whether or not there are habitable planets around other stars in our galaxy, and the degree to which we think that are habitable and what we know about them is quite a stretch, because looking from a distance is not the same as being there, and being able to look personally.

DR. BARLOW: Although, of course, we have actually identified planets around other stars in habitable zones that look similar to Earth.

DR. MEYER: Yeah -- that look like they should.

DR. BARLOW: Yeah.

DR. MEYER: And so that's -- and the refinement of that is going to be a tremendous amount of science.

But I'll throw out a caveat: It's one of those -- I used to be the Planetary Protection Officer for a while. And one of the interesting things is that the rule used to be that if you're going to send an orbiter to Mars, you don't want to infect the planet, so you have to guarantee -- within 95-percent confidence limit -- that your orbiter is going to remain an orbiter for 50 years. Otherwise, if the orbiter's not going to last that long, you're going to have to sterilize the orbiter, so you don't, you know, infect Mars with Earth life.

So, you're looking into it, saying, "Why 15 years?" You know, that's kind of a number out of the hat. Well, essentially, when the planetary protection rules were established, it was the, "Well, by 50 years, we're going to have humans onto Mars. We're going to have everything like that, and the game will be over in terms of worrying about contamination on Mars, because we'll have, you know, people there, tromping around."

Well, that was --

MR. WEST: And probably dropping trash everywhere.

DR. MEYER: That was, you know, a little bit before the time of Viking. And we saw how well that's worked on getting humans on Mars in 50 years.

So, the caveat is, of course, what we think we're going to know in 25 years from now is a projection of what kind of scientific progress we've been making up to this date -- but whether or not it keeps on going.

MR. WEST: Okay. We have time, I think, for a couple more questions.

This gentleman right here -- there's a microphone coming over to you.

QUESTIONER: My apologies if this question has already been asked. What are the rate-limiting steps, other than money, to get a human being to Mars? And what are the steps that are being taken to solve those problems?

DR. MEYER: Well, I mean, part of it -- it's not even money; it's resolve. You know, whether or not you want to do it, and how fast you want to do it. And so that does translate into money, but I think it is resolve.

There are -- depending upon who you talk to, you can go right now. And, in fact, obviously, Mars One says you don't even have to come back. So, that makes it a lot easier.

But it's basically a degree of risk. And, interesting enough, we have Jason Cruzan here, who has a much better idea of what the engineering steps are to go from where we are now in the space program to actually getting humans to Mars. If he wants to --

MR. WEST: Jason, you want to chime in there? And introduce yourself, so --

DR. MEYER: And by the way, that was my phone a friend thing.

MR. WEST: And introduce yourself, so we know who you are.

MR. CRUZAN: Yeah, I'm Jason Cruzan. I work in our Human

Exploration Operations Group. And I actually run the architecture planning for humans to Mars and planning.

So, I mean, there's -- Mike really hit it. It's the resolve factor, but it also means, do we go once or multiple times? And that really fundamentally changes the engineering choices you make. If we wanted to go tomorrow or go quickly, you make certain fundamental changes -- or decisions in engineering -- to go quickly, and you won't make the investments that you need to go again.

So, it's really -- that dialogue that we need to have is, are we going to really just explore once, or really go into Mars to pioneer, and actually think about living off of Earth on extended periods of time? Because if we just want to go once, I'm sure we'll want to go again.

And scientists like those here on the stage that we're listening to -- the only thing they'll want to do is go again, I'm sure. There's always going to be another question.

So, that's the real basic answer you want to look at, is how to make those engineering choices as a function of how often -- and, really, to go to stay and pioneer into deep space. So --

MR. WEST: Okay.

MR. CRUZAN: So, you can make fundamental choices -- the question is on propulsion system choices. Do you launch all your fuel from the gravity well of Earth and go once? And the technology is nearly there today to go do that type of mission.

Or do you think about how to do living off the land, and actually create propellents in -- off of asteroid material, lunar material, or even Mars surface -- in order to actually create propellants -- hit different gravity wells or different locations in space, in order to make that propulsion trade work. That's one of the areas.

Also, if you can gather more water, water could equate to radiation shielding, allowing humans to actually survive productively in space for a longer periods of time.

So, those are a couple of the key areas. So --

MR. WEST: Okay, thank you. No, that's very helpful.

I think we have time for one last question. This young lady up here has a question. So, this has to be a really good question, since it's the last one.

DR. BARLOW: No pressure.

MS. BALL: Thanks. I'm Jessica Ball, from the Geological Society of America.

And my question has to do with the instruments that you used to do this exploration. So, in the past, you know, couple of decades, we've seen things like the Mars rovers outlasting their original mission parameters by years, even -- which is fantastic. But that sort of brings in the question of, how do you balance wanting to use these to the full extent of their abilities with the need to get the next big thing up there -- the next rover or the next instrument?

And the reason I ask this is because we see Congress asking, well, why should we spend money on this new thing when we have this thing that's already still working?

MR. WEST: Actually, that's a great closing question. Thank you.

DR. MEYER: Yeah, that is. So, one thing is, the cost of getting something to Mars is tremendous. I mean -- and so once you're there, the cost of continuing that operation is on the order of $2 million -- or, you know, tens of millions of dollars, depending upon the complexity of the mission.

And that's just a huge benefit. As long as the instruments are working, you're getting new science, and, you know, as Steve Squires would say, you know, every time you go over another ridge, you have a new mission; you're exploring a new spot on Mars.

So, in many ways, we don't have the same difficulties of the cost of maintaining what we have now operating as eating into a significant part of what we'd want to do next.

And speaking of what we want to do next -- a good example of why you want to improve on instrumentation and why you want to send the next thing is because of that capability that you don't have with the current version.

One of the things I'm extremely pleased at is, on the Curiosity, we have this instrument called ChemCam, which is a laser-induced breakdown spectrometer. And it zots laser things within seven meters of it, and it gives you the elemental composition of whatever it zotted.

And it can do it in very fine scale. You've got a distribution. It's a fantastic survey tool, where, if you had to do that with our current suite of contact instruments or analytical laboratories, it'd take you several months to analyze the same number of rocks in the area that this thing can accomplish in a day or two.

So, it's the improvement in the technology of the next instrumentation that you want to send that is part of the helping you -- drive you to want to do the next mission.

The other half of it is, you learn more. You now have a better idea of what place on Mars would have an even bigger payoff than the last place you went, because now you have a better understanding of what the environment was like early on; what places may have preserved the best record of that history.

DR. BARLOW: I think an excellent example of that is -- I remember being at the landing site workshops for the Mars exploration rovers. And I was sitting next to Mike Carr, who is the, you know, imaging team lead for the Viking missions back in the 1970s.

And during the landing site selection workshop, you know, everyone's getting up there saying, "Okay, well, you know, from this mission, we now know that this is the rock distribution. And from this mission, we know what the dust distribution -- and from this mission, we know that this is a really exciting area because of X, Y, Z."

And Mike is just sitting there, kind of going, "We never should have succeeded with Viking. You know, we didn't have any of this information. And why did we, you know, choose the sites that we did?" Well, they were smooth. They looked like they would be places where we could actually successfully land, and that was our major concern.

Now we're to the point where we're actually pinpointing exactly where we're going to go. The landing ellipses for these guys have shrunk dramatically, as Mike can tell you, for Curiosity. It was just right on where they expected to land.

And we can very precisely pinpoint exactly where we want to land, what we want to do, where we want to go, in order to answer those questions. And we couldn't do that without the advancement with all the technologies and just the new instrumentation that we actually had.

MR. WEST: Well, I want to thank both Michael and Nadine. We really appreciate all of the great work you're doing, and we wish you great luck in the future, as well. Thank you very much.

DR. BARLOW: Thank you.

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