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Pilot, Not Passenger: Canada's Role in Space

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15TH ANNUAL CANADA-UNITED STATES LAW INSTITUTE DISTINGUISHED LECTURE: PILOT, NOT PASSENGER: CANADA'S ROLE IN SPACE

Professor Michael Byers

The following is the text of the 15th Annual Canada-United States Law Institute Distinguished Lecture, delivered by Prof. Michael Byers on 26 Oct. 2022 at the University of Western Ontario Faculty of Law. Professor Byers holds the Canada Research Chair in Global Politics and International Law at the University of British Columbia. He also co-directs the Outer Space Institute, a global network of space experts.

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So fantastic to see such a young audience. This is why I teach. I'm going to take you on a bit of a journey in the next forty minutes or so. I'm going to leave as much time as I can for interaction with you, so save up your questions or your opinions. It doesn't need to be a question. If it's an opinion, just keep it respectful and short. We have a lot that we could talk about today. This is a topic that I care a great deal about, and it's one that will shape all of your lives in quite fundamental ways. So, let's start.

The title of my talk is 'Pilot, not Passenger: Canada's Role in Space.' I don't know if any of you got the reference there to a line in a fantastic movie about the American astronaut program. The line is from The Right Stuff, spoken by the actor Scott Glenn who played Allan Shepard. And Shepard says to the German-American rocket designers, and I quote, 'that is a spacecraft, sir. We do not refer to it as a capsule.' Making the point that they were pilots, and not passengers-that even the early spacecraft had to be flown, and that in this particular case the astronauts were insisting that it had to have a window. Now, when you hear that title 'Pilot, not Passenger,' some of you may have thought that I was referring to the United States and Canada, and particularly the relationship between the Canadian Space Agency and NASA, because the Canadian Space Agency in Canada in space has generally been the junior partner in exploration activities. We build a lot of high-tech pieces of equipment that go onto NASA spacecraft, and you might legitimately have thought that that would be the focus of my talk. Well, we could talk about some of that, and when we get to the discussion phase someone might ask me about the prospects for a completely Canadian space mission. I would love to talk about that. But the focus of my initial half hour of comments is actually going to be a little bit different. It does concern Canada and the United States, but in a different way, because I don't want to talk about spacecraft in the sense of pieces of metal and electronics constructed by humans to send into space. I want to talk about the spacecraft that we live on called Planet Earth. Now this is

not a unique insight. You've all heard about Spaceship Earth. You all know about the famous photograph 'Earthrise'. And you know about the pale blue dot. This recognition that Planet Earth is our spacecraft in the infinite universe is one that's been talked about for at least a century and a half. But I want to make an argument for all of you who are law students that international lawyers from Canada, the United States, and elsewhere have major roles to play in the safety and sustainability of this planet and of our species in space. That the future of humanity in space has to be significantly a legal and a government's activity, and not one that we leave to the space scientists, and the engineers, and the corporate titans that want to dominate outer space. But, the lawyers are an integral and necessary part of humanity's expansion into the final frontier. And I'm going to make this argument by talking about the main topics that I have addressed in my research and in my writing over the course of the last four years. And a very important credit at this point, all of my space research now is done in full partnership with an astrophysicist named Aaron Boley at the University of British Columbia-everything that we do now is fully co-authored, including a book that's coming out in January entitled 'Who Owns Outer Space?' So, everything I talk about is not just me; it's my understanding of a very challenging collaboration between an astrophysicist on the one hand and a lawyer/political scientist on the other. I have literally broken my brain on hundreds of occasions in the last four years to try to understand the physics. It's not easy. But nothing that we publish includes an equation that I do not understand; I insist on understanding everything in our papers, and Aaron does the same, as he rapidly becomes, I believe, a fantastic space lawyer.

So, let's talk about things that we've been doing. And I'll start closest to the surface of the earth and move outwards, just as a way of organizing this. So, is anyone here planning a trip just a little bit to the south of here in about, oh I don't know, two or three weeks' time? Let's imagine that you're going to spend a weekend in New York City. And in roughly two or three weeks' time, there might be a risk associated with traveling to 41 degrees north-we're at 42 here in London, Ontario-but traveling to 41 degrees north in two or three weeks' time might actually introduce a risk into your life that you were not aware of until I just told, right now. Because in the next couple of days, the Chinese Space Agency is going to launch a long march 5B rocket carrying a module for its new space station, the Tiangong-1 Space Station. And this rocket, which is rather large, has a core stage, a main stage, that will be abandoned in low-earth orbit. And because the orbit is rather low, it will encounter gas drag, the upper regions of the atmosphere, which will then bring it back to earth roughly two to three weeks after the launch. Now this core stage weighs twenty tons. And significant pieces of it will survive re-entry, and in fact we know this because they've done this on three occasions in the last couple of years, and on two of those occasions, pieces were actually discovered on the ground in the Ivory Coast and most recently in Malaysia, I believe. So, 20 tons of rocket stage is going to be coming back to earth, and because of the inclination of the space station, and therefore the launch and the orbit in which the stage is abandoned, the risks are highest at 41 degrees north, 41 degrees south. Ergo New York City. Imagine what a 20-ton rocket stage, even

broken into large pieces, would do to Central Manhattan. That's what we call a low-probability, high-consequence event, because chances are that it will land in the ocean somewhere. But as I said, two of the last three actually resulted in pieces on land.

It would be easy to criticize the Chinese for this. It would have been relatively easy to design this rocket in a way that enabled a controlled re-entry; in other words, engines that could be re-started with enough residual fuel to bring the stage back into a re-entry that ensured that it would land in the middle of the ocean. Ideally, the south Pacific Ocean, which is actually a spacecraft graveyard-that's the unofficial name for an area of the southern Pacific Ocean that is used for controlled re-entries. But the Chinese space agency, for whatever reason, decided not to go through the trouble of designing a controllable rocket stage, and instead are abandoning these in orbit. They're not the only ones who do this. There are stages that are abandoned because they cannot reignite their engines some boulder rockets that are still in use, and there are other rockets that are able to engage in controlled reentries where the operators choose not to do so in order to maximize the performance for their customers. SpaceX very famously has pioneered landable first stages, and generally does controlled reentries with their second stages, but from time to time we'll abandon this stage in orbit in order to maximize the performance to be able to lift the customer satellite as high as possible. And as a result, we have a lot of rocket stages that come back to earth or will come back to earth in the years ahead, including stages that have been up there, in some cases, for decades. So, there are literally hundreds of rocket stages, some of them dating to the Cold War era, that will come back at some point, and will have pieces that survive. One of the things that Aaron and I have done working with one of our PhD students been to begin to look at this issue; first of all, to identify that with available technologies and with available mission design you can pretty much have a controlled reentry regime of the vast majority of rockets that are currently being launched or in the future being launched coming back through controlled reentries - that is possible. The other thing we've identified is that the burden of risk is carried predominantly by countries in the global South. Historically, most of the rocket bodies abandoned in orbit and many still today are ones that are used to launch to geosynchronous orbit near the equator, to launch to 36,000 kilometers up where the satellite then rotates at the same speed as the earth and therefore is about the same location on the planet to provide things like satellite TV. And we've actually plotted the geographic distribution of risk and discovered that the risk is roughly four times higher if you live between 30 degrees and 30 degrees south as opposed to living in one of the major space fairing states- the United States, Russia, China, and Europe if you want to talk about Europe as a whole being a major space fairing state.

So, what's been happening for decades is the major space fairing states, the big countries of the North, have been accessing space using the cheapest available method, which is disposable rockets, and imposing the pollution risk, the safety risk, on the countries of the global south. Now, does that sound like any other topic that you might be aware of? Like carbon dioxide emissions? It's a standard exploitation- the externalization of your costs onto people who are not

beneficiaries of your activity. And so, one of the things we called for is for the countries of the global south to insist on a controlled reentry regime, to have a multilateral process that leads to an agreement that there must be a transition to all rocket body re-entries being done in a controlled manner. Now someone here in Q&A is probably going to say: well, is that really possible? And my answer to that is yes. So, prior to 1989 on the oceans the majority of oil tankers only had a single Hull. That's because industry says it was too expensive and too difficult to have double hulls; it just wasn't practical, and how could you get everyone to agree to a double hull requirement anyway? This is a transportation issue in an area beyond national jurisdiction not dissimilar from space. Singe hull tankers – that's what industry wanted, and is what industry got, until the Exxon Valdez accident off the southern coast of Alaska, which decimated an otherwise pristine coastline, attracted a massive amount of public attention and outcry. And in response to that, the U.S. government unilaterally banned all single-Hull tankers from U.S ports. Within two years, the international maritime organization had adopted the same rule and modified the relevant conventions, and today ninety-nine percent of tankers on the world's oceans are double hull as a matter of international law and industry practice. So, if the shipping industry can do it, if we can transition to a safer regime with regards to oil tankers, why can't we transition to a safer regime with regards to rocket boulders? It might seem like a small problem, but given the dramatic increase in the number of launches and the fact that it is an externalization of risk issue onto the global south, I think there's real potential. If we can do it, why shouldn't we? And it has to be done through the law, because if you don't do it through international law, you will get what are called 'free riders': or to adopt the language of the law of the sea, you will see flag with communion states, big potential issue in space as it was on the oceans. So, rocket wise, our next project on rocket bodies is the risk to civilian airlines. I could really have you worried for your next flight, if I took the time.

The next issue I want to talk about are satellite mega constellations; and here, I am speaking most centrally about Starlink, which is a system of communication satellites in low earth orbit that's being built by SpaceX, which of course is controlled by the richest person on the planet-and sometimes the most erratic person on the planet-Mr. Elon Musk. I tell my students when I teach my course on space governance that the course is driven by Elon Musk, and every issue relates to him-I've already mentioned his landable rockets. SpaceX is now responsible for half of the operational satellites in Earth orbit, and this has all happened in just the last two weeks. So, we have roughly 7000 operational satellites in orbit. I haven't counted the latest number of Starlink satellites; they launch roughly 50-55 per week on average, but the number is going up dramatically. They have licenses from the U.S Federal Communications Commission-that's a national regulator, not an international regulator-for 12,000, and an application that is in the works for thirty thousand more. And these are not small satellites; current ones are approaching 300 kilograms per satellite, and they are designed to provide broadband communication anywhere on the planet with very low latency, very little time delay, eliminating the tiny but problematic delays that come with communications from geosynchronous satellites at 37,000 feet. These satellites are

low down, they're 350 to 550 kilometers above the planet. And the idea of having broadband accessible around the planet is really exciting if you live in a small community in Canadian Arctic, for instance, or if you are a mariner at sea, and there are lots of people in remote and rural areas who are deservedly excited about the prospect of this technology. But it does come with problems; and Mr. Musk is very much a product of the Silicon Valley culture of moving quickly and breaking things, and learning from breaking things - making mistakes - and that's why he was able to develop landable rockets so quickly, by actually having lots of accidents as he tried to perfect it. And the Starlink mega constellation is an exercise of learning through doing, and it is premised upon what's called the 'consumer electronic product' model. So how many of you have a cell phone that's more than five years old? The old guy at the back. Yeah, I had one of those just until a week ago. But the idea is that if you have a system that results in rapid turnover, you can transition to newer, better technology very quickly, and therefore improve your systems, and therefore stay ahead of the competition. So, the idea has been extended from the consumer electronic world now to space, with every single one of SpaceX's satellites designed to have an operational lifespan of only five to six years. And you could only make this model work if your launches are really cheap - i.e. land-able rockets that you can reuse again and again - and if you're prepared to overlook some of the externalities that are associated with this.

So, externalities associated with mega constellations. It's a great idea, wonderful for remote communities, for instance, but, there are certain problems. One of the greatest externalities is being born by the astronomy community in the form of light pollution and also radio pollution, because these are communications satellites, and a significant part of astronomy is done with radio telescopes. But it wasn't until 2019 that the astronomers realized they had a problem, when an image from a telescope in Chile was damaged by a streak of light from one of the first Starlink satellites. And very quickly, the international astronomical community has organized to try to push back against this existential threat to the world's oldest scientific discipline by trying to, among other things, encourage SpaceX and other satellite companies to mitigate some of this light pollution. And the companies - SpaceX in particular - have tried to work with astronomers. Right now, they're putting visors on their satellites to reduce the glare. The biggest problem is that these satellites in the night sky will often catch sunlight that's coming around the planet. So even though it's dark where the telescope is, the astronomers are looking into the deep universe, you have a satellite that's going across the sky that's catching the sunlight that's coming around the planet and it's lit up like a Christmas tree. And that, in itself, can cause a streak across your image or just the proliferation of this can simply raise the ambient light in orbit and therefore what you need to look through. And if you get enough of these satellites, all of a sudden you start to get them actually obstructing, by their sheer physical presence, what's called an occultation, actually impeding the image. So that's an externality that I'm pretty sure Elon Musk had not thought of when he designed this.

But there are others. One of the issues is that many satellites, when they re-enter at the end of their lifespan, or if they're abandoned and not actively brought back, when they eventually are brought back naturally through gas strike, many of

them have components that survive re-entry. SpaceX with its first generation of satellites claimed to have avoided this problem by building their satellites almost entirely out of aluminum, so they'd burn up completely. But now they're proposing to build much larger satellites, in excess of 1,000 kilograms, and it's hard to imagine that there won't be components that survive from those. So just like the rocket bodies, we have a casualty risk associated with these.

But, there are other issues, and I won't touch on them all because they get more and more complicated. There's a climate change issue, and you would think automatically that this has to do with the launches, and it does. You have the combustion of the rocket engines, particularly in the upper atmosphere. They do a lot of damage, a lot of potential risk, for instance, to the ozone layer. And that wasn't an issue when launches were relatively rare, but now there's a launch almost every day somewhere on the planet, and so the issue of climate impacts on launch is growing. But perhaps the issue of greater concern with regards to climate change are the actual re-entries, the so-called burning up of these satellites. So, imagine you have 40,000 satellites in the Starlink constellation, the SpaceX constellation, and let's imagine that they are being de-orbited actively-which is a relatively responsible thing to do, it's what SpaceX is doing - at the end of a five-year life cycle. How many satellites are re-entering each year? 40,000 divided by five, that's 8,000 satellites a year coming back and burning up in the atmosphere. Now, if each of them is 300 kilograms of aluminum, that's a lot of aluminum. It is going to dramatically increase the amount of aluminum particles in the upper atmosphere. This exercise of actively de-orbiting satellites that are designed to burn up entirely are going to dramatically increase the amount of aluminum particles in the upper atmosphere.

Now, it just so happens that proponents of geoengineering - so using engineering to save the planet from climate change - have been floating the idea of deliberately depositing large amounts of aluminum into the upper atmosphere so as to reflect solar energy back into space. And Elon Musk is enough of a visionary that I can imagine him actually having identified that all of his Starlink satellites, by burning up in the atmosphere and adding all this aluminum, might actually be doing something positive with regards to climate change. He cares about climate change; that's part of the motivation behind Tesla, right, is to change the world automobile fleet to a more climate friendly version. And he's not the sort of person who believes in peer review or government approval for what he does. So, it's possible that he is engaged in a geoengineering experiment as a side consequence of his building a mega constellation in space to dominate global telecommunications and fund his mission to mars. And perhaps not; perhaps he hasn't thought of this, but that doesn't mean that it's not happening and that it's not a potential problem, and that maybe we should have some serious science on this and have some government assessment of the risks associated with this plan. Now here's the thing: the U.S. national regulator, the Federal Communications Commission, decided some years ago that it did not need to do an environmental impact assessment of the Starlink constellation, because space is not an environment. As you can see, there's a problem. First of all, space is an environment. Secondly, the atmosphere is an environment, and all of it is part of

our planetary environment in very direct ways. There's no bright line between the earth, environment and space; It's a spectrum going out and depositing massive amounts of aluminum in the atmosphere is an environmental consequence of an activity that the FCC decided didn't need an environmental impact assessment. There's a case that's been going through the U.S. Federal Court on this precise issue, taken unfortunately by one of SpaceX's competitors that has an obvious interest in derailing SpaceX not for environmental purposes, but for competitive reasons.

And then there's the issue of space debris, which I'm sure you've all heard of by now. Low earth orbit is becoming very crowded. SpaceX is going to make it much more crowded, and they're counting on automatic collision avoidance technology to avoid collisions of their 12,000 or 40,000 satellites in space. And Elon Musk is actually on the public record as saying that with collision avoidance technology you could put up to a billion satellites. Now, that assumes a while bunch of things. First of all, that there's only one operator; secondly, that there are no failures, right, because a failure is a dead satellite that cannot be controlled; and it also ignores the fact that not only are there big pieces of debris that we can identify and track-at the moment down to about eight or ten centimeters in diameter-but there are millions and millions of pieces that are too small for us to track with ground-based RADAR, and even in the future with better, space-based, space-situational technology. And a piece as tiny as a paint fleck can destroy a satellite, or punch a hole in an astronaut's spacesuit during a spacewalk. And Elon Musk seems to be willfully ignoring the untraceable, lethal debris issue with regards to this constellation.

And there are other issues, but we have a case here where you have a company, owned by the richest person on the planet, that is moving so quickly that it is ahead of the regulators, it is ahead of the development of new international law. And you can look at the situation and imagine the kinds of rules that you would want to have to govern this kind of activity, to deliver the benefits while guarding against some of the risks. Like a rule that said that you have to have an environmental impact assessment before a project like this. And one could imagine a scenario also where satellite companies were required, both domestically and internationally, to not use the consumer electronic product model; to do what they want to do with a smaller number of longer lived, higher quality satellites with higher capacity, that would have redundancies built in, and that could actually be used for ten, fifteen, twenty years. Canada's major space company, MDA, has a fantastic satellite that is in orbit right now, doing exceptionally good work, that was launched in 2007; RADAR SAT 2 is fifteen years in. That is redundancy; that is resilience built into the system. It's expensive as a unit, but that kind of approach, a different approach, solves some of the externality problems here. I'm conscious of time.

Anti-satellite weapons. I've told you about space debris; well, you can make the space debris situation worse by not only having accidental collisions from time to time, but actually having intentional collisions. And in the case of an anti-satellite weapon, that might be one satellite intentionally colliding with another-or, more likely, a ground-based missile targeting a satellite in space. And indeed,

in November of 2021 Russia used a ground-based missile to destroy a Soviet-era satellite at an altitude that was quite close to the International Space Station. Now, the debris kicks out in every direction, because the high-energy impact - I mean we're talking about a combined velocity of over 30,000 kilometers per hour, right? Massive jolt of energy, debris going in all directions, but particularly heavy debris at the altitude of the collision, and close to that, and just two days ago the International Space Station had to do a thruster burn for five minutes to move out of the way of a piece of trackable debris resulting from that test, from that Russian anti-satellite test from November. So, one way that you could make the debris issue really bad, really quickly would be to have not just testing of these weapons, but their use in actual armed conflict. And it gets worse, because at some point if you have enough debris, you get what are called 'collisional cascades', where pieces of debris start colliding with other pieces of debris or active satellites, and they create more debris, which increases the risk of substantive collisions, because every time you have fragmentation you increase the overall surface area of the material, which increases the risk of further impacts, and you get what's called the 'Kessler Syndrome' of runaway space debris which could in the course of the next few decades if we don't do something about this, render significant portions of low earth orbit inaccessible, unsafe for a long period of time. And we need low Earth orbit for all kinds of reasons; everything from imagery for disaster relief, to food production for agriculture to fisheries, it just goes on and on. I mean, we are so dependent on this global commons of low Earth orbit that having someone engaged in kinetic warfare would be to destroy very significant human interests. And I would suggest that part of the reason we haven't seen the use of anti-satellite weapons in warfare yet is because the major spacefaring powers are aware that this is a kind of mutually-assured destruction; that they destroy their own interests in space at the same time that they're targeting others. Space debris does not pick and choose its targets. We can talk more about that if you want, particularly in the context of the Ukraine war during the questions.

I'll talk very briefly about space mining - couple of faculty members here at Western that are working on space mining - simply to say that space mining is another issue where we have a strong industry, based in the United States predominantly, seeking to capitalize on the potential of extracting and using resources in space. And the most exciting prospect in space is not actual minerals in the sense that we normally think of them, but water ice; the prospect of using water in space to make rocket fuel that doesn't need to be lifted out of Earth's heavy gravity. And there's a lot of water in space, it turns out. We're discovering more of it all the time, including on the moon, and on Mars, and on some asteroids, in the form of ice. And this issue of space mining parallels in many respects the issue of deep sea bed mining, in another area beyond national jurisdiction, where we have seen for decades an ongoing lawmaking struggle between mostly the United States and mostly the global south on the other side seeking to determine whether this is something that is available for exploitation by private companies for profit, or whether to some degree it needs to be multilateralized with benefit sharing going to the non-technologically capable states. If this is a global resource,

or a common resource, then the global south would say that there needs to be benefits that flow to everyone.

Now, the country that is most able to further its interests in international diplomacy and law-making is the United States. A decade ago, I actually counted how many international lawyers work for the U.S. Government, and I got to over 700 people who do international law for the U.S. Government. They're very, very good - if you want to learn how to become a good international lawyer advancing policy, study what the United States does. It's highly strategic, very sophisticated; full credit to my friends and colleagues at the U.S. State Department and in other departments and agencies that do their work so well, do their work for the interests in the United States. And because of the way the U.S. Government system works for the powerful lobbying interests that operate in Washington on behalf of Industry. Just the way it is. It also happens that on issues like deep sea bed mining, that from time to time the global south collectively bargains against the United States. And so, you have issues that play out in places like the United Nations where you have the global south coming together, usually through what's called the G77 - Group of 77 - which now is made up of 133 of the 194 member states in the United Nations, and they collectively bargain against the United States. And sometimes they manage to shift outcomes. So, we have something called the international sea benefit. We have something called Part 11 of the United Nations Convention on the Law of the Sea because of this collective bargaining by the global south. And right now, with regards to space mining, we're in the same kind of lawmaking moment, where the United States is pushing forward with something called the Artemis Accords, seeking to advance a position where the commercial exploitation of extracted resources is widely accepted internationally. On the one hand, they're pushing it through something called the Artemis Accords, building a coalition of allies that can be persuaded to sign on to this, sometimes in return for astronaut slots on NASA spacecraft; and on the other side, you have the global south, coming together and beginning to collectively bargain on this issue and pushing for multilateral negotiations that might, in the end, result in some kind of global regulation of this activity and some degree of benefit sharing. That's where we are right now. And all I can say here is that, thanks to the global south, thanks to the G77 plus China, we now have the beginning of multilateral negotiations on this taking place in a working group established under the United Nations Committee on the Peaceful Uses of Outer Space. So, I'm not expressing a personal opinion here, but describing the landscape in terms of international law. Now, it's curious that Canada is one of the countries that has signed on to the Artemis Accords and chosen to take a position on one side of this issue.

Okay, very briefly: planetary defence. I don't know what planetary defence is, but just two weeks ago, NASA struck an asteroid - or actually, more specifically, the moon of an asteroid - with a small spacecraft in an attempt to alter its orbit around the asteroid slightly. It was successful; we have actually changed the orbital dynamics of a celestial body for the first time, as I understand it. So, we have left our mark on the universe as a species, in that respect. But we've also demonstrated that, in an emergency situation, we could smash the spacecraft into an asteroid that was on track to strike Earth, and hopefully change its trajectory slightly, change

it's velocity so that it misses Earth. And this is actually more of an issue than most people realize, and we will collectively as a species come to an even greater realization in the next few years, as more and more of these near-Earth objects are identified thanks to new telescopes. And at some point - hopefully not in your lifetimes, but at some point - we are going to have a dangerous asteroid identified that is on course to strike Earth. Now, whether it's 150 meters across, or 350 meters across, or 10 kilometers across like the one that destroyed the non-avian dinosaurs, we don't know yet. We're working very hard as a species to identify these objects; most of the really big ones we think we've identified now. It's hard to spot the ones that are coming from the direction of the sun, or coming from the opposite direction of the sun, because they don't move much relative to the stars. In 2013, a small asteroid blew up on striking the atmosphere above a Russian city, Chelyabinsk, and over 1000 people had to go to the hospital because of injuries, mostly to their faces and their eyes, because they saw a bright flash outside and rushed to the window to see what it was, and then the shockwave hit the windows of their house and the glass shattered. That was a small asteroid, but in response to that incident, the international community established two bodies: one was the International Asteroid Warning Network, the collaborates on identifying these, and the other is the Space Mission Planning Advisory Group, that built out mission plans for what you would do or what you should do if we get into a situation like this. There are all kinds of issues associated with this; some of them involve lawyers. The big question with regards to lawyers is, who decides? Who decides to attempt an asteroid redirection? Is it the United Nations Security Council? This would be a threat to international peace and security, a large asteroid on track to strike Earth. Can the Security Council agree, or not? If the Security Council can't agree, can one or more states decide to proceed unilaterally? Which government department or agency takes the lead on this? Is it the space agencies, who actually know something about asteroids, or is it the military, which tends to lean forward in these situations, and tends to be by far the most powerful department in any government, in terms of political power? Now the good news here is that an intercontinental ballistic missile cannot achieve escape velocity, so it cannot be used for a planetary defence exercise. They need the spacecraft to do that. But one can imagine all kinds of legal situations arising with regards to the issue of who decides, and then issues arising with respect to, for instance, liability; what happens if you redirect the asteroid only slightly, and it hits another country that it wasn't going to hit before you intervened? Who's going to compensate India for the loss of Mumbai, for instance, and what does international law have to say on that matter? You get into all kinds of what look like extreme hypotheticals, but they're perhaps not as hypothetical as the non-scientists would think. And I will close with that; there's so much to talk about, but I will close with a plea to all of you who are interested in working on international law and pursuing careers or further studies in it: context is everything, and in the context of international law, the scientific context is essential. If it's in the ocean, you need to speak to the oceanographers, rights? In space, you need to speak to the space scientists. If you're working on climate change, you need to speak to the atmospheric scientists, right? You need to understand the context in which you operate. One of the biggest

challenges, and for me the most intellectually rewarding aspects of working on space, is actually learning about the incredible complexity, not beyond our planet, but the incredible complexity which our planet is. And that, I guess, is the point I would end with. There are no sharp lines in our universe-everything exists on the spectrum, and everything is connected in all kinds of essential ways. And that's the same thing between disciplines; the scientists, and the engineers, and the generals, and the admirals, and the politicians, they need you. They need the lawyers in order not just to give them the laws and regulations, but to help them get to those outcomes through the negotiations that are involved, and also, in so doing, to devise better rules, better procedures, better institutions than anyone might have intuitively thought possible. And I come back to the Exxon-Valdez and the double-hull anchor; I could give you the example of the Montreal protocol that eliminated 98% of the chlorofluorocarbons that go into the atmosphere, and is now saving two million lives per year globally from skin cancer. International law can work in highly effective ways; most of the time it doesn't, for other reasons, but when it does it's beautiful, it's brilliant, it's an essential part of human purpose, and you are all the future of that. Thank you.