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I: Hello and a warm welcome to IFLScience, the Big Questions. I'm senior journalist Tom Hale and I will be your host for this episode. Today I'm going to be chatting to Scott Solomon, teaching professor of bioscience at Rice University and we will be asking the question; when will new species of human evolve on Mars? In his 2016 book, *Future Humans: Inside the Science of Our Continuing Evolution*, Scott looked into the myriad of ways in which *Homo sapiens* might evolve on our journey ahead. He is currently writing another book, *Becoming Martian*, that explores how the colonisation of Mars might influence our species' evolution.

I: Hi Scott and welcome to the podcast.

R: Hi, happy to be here.

I: It's great to have you. To get things going, it might be good to just address some of the misconceptions people might have about evolution. In the 21st century most of us don't have to hunt for food, we don't have to take down a mammoth to get a bit of protein, likewise there is plenty of medicines we can take if we get sick. So in that sense, are we still subject to natural selection? Are we still evolving in that classic sense?

R: Yeah I think it's a great question and it's an important question and I think the answer is quite clearly yes. Really, I would sort of tease that into two separate questions 'cause you asked is natural selection still operating and are we still evolving. Actually as an evolutionary biologist I would argue those are actually distinct. So obviously, natural selection is one of the ways that evolution can happen. That's what Darwin gave us, right? He argued this is the mechanism by which evolution operates but he never actually claimed it was the only mechanism and he himself came up with a second mechanism during his lifetime called sexual selection and that's how differences in mate choice and how many offspring an individual has, that can influence evolution. Then after his lifetime, biologists came to recognise several other ways in which evolution can happen and so now we would argue that evolution isn't optional. It's not like a thing you can turn off. No species can ever really stop evolving, but you do make a good point about natural selection operating in a fundamentally different way in the modern world because, as you pointed out, yeah we've got modern medicine. Many of us, at least, have access to modern health care and abundant food and clean water and all of these things that really sort of take that survival element out of the quote-unquote "survival of the fittest". But here's thing, right. As long as there are differences in survival that have anything to do with genetics there is going to be some natural selection and we know that there are. We have actually seen that in the pandemic. We know that there is some variation just in how much resistance individuals have to infectious diseases, even brand-new infectious diseases like

COVID-19 that presumably nobody until 2019 had any exposure to them and yet we still see some differences from one individual to the next in how severe the infection is. So that kind of thing alone can allow natural selection to continue to operate. So I would say yeah, natural selection is clearly still operating in the modern world but there are also other forces of evolution that are still operating. One of them, I think, is maybe the biggest, the strongest in terms of how it's affecting us today and that's the movement of genes from one population to the next. So we call that gene flow in evolutionary biology. Once upon a time human populations living in very different regions of the world, like on different continents were relatively isolated from one another. It was very unlikely that an individual is going to move between them, if you go back more than 5,000 years ago say, and so now in the modern world it's not the case anymore. People easily move around from one place to the next and take their genes with them of course, and so that movement of genes between populations is actually another mechanism by which species evolve, so yeah, we're definitely still evolving through natural selection but through other mechanisms too.

I: Fascinating. So obviously that what you're talking about is applying to today's world and you mentioned how we can still see it in just the way different people are migrating and moving to different parts of the planet but in the century ahead, we are potentially going to face a huge change in the sense that we might potentially set foot on Mars and colonise another planet. So how will that change things?

R: Yeah, so I think there is a lot of reasons to believe that if humans ever successfully create settlements on other planets, like a permanent self-sustaining settlement, say, on Mars that that would take us on a different evolutionary trajectory, different fundamentally from what would happen if we just remain here on Earth. For one thing it might prevent us from going extinct so you might argue that's a good thing if, say, there was an asteroid impact that destroys our planet or makes it uninhabitable, but beyond that, I think it would lead us towards a path where people living on that other planet, let's just say Mars, they would start to adapt to the conditions on that planet. We should expect that because we know from studying evolution here on Earth that any time a few individuals make it to a new place, say, an island in the ocean, right, they will start to adapt to the conditions on that island. I mean, this is the reason why islands have been so fundamental to our understanding of evolution. This is why when Darwin went to the Galapagos Islands it has such a big impact on him because the effects of evolution are so clearly seen in island populations and at the end of the day, planets are like islands right? Just on a much bigger scale of course. I think we would expect people who are living on Mars to adapt to the conditions on Mars which of course are very different to the conditions here on Earth and they would start to maybe look different, maybe have some different aspects of their biology, of their genes and other things that we can talk about but yeah I think it would lead to a big change in our evolutionary future.

I: Yeah for sure. I mean obviously this might require some speculation but have you imagined ways in which it could change the visible traits of people, the biology of people who have moved to Mars?

R: Yeah. Actually this is something that I have been working on for a number of years now. I got really interested in this idea that humans living on other planets might evolve differently. Soon

after my book *Future Humans* came out in 2016 and at the very end of that book I sort of put this idea out there, the way we are talking about, like "Okay would this lead to a different possible future?" And I think the answer is clearly yes, and so ever since then I've really been doing a deep dive into asking exactly that question. I'm actually working on a book right now for MIT Press all about those types of evolutionary changes that could happen to people if they were successfully able to create permanent settlements on Mars. So, yeah, I think there is a few things we can think about, right. So, one is what are the major differences between Mars and Earth in terms of the environment itself? One of them is that Mars is smaller and being a smaller planet it has a little bit less gravity than earth, in fact it has about one third of the gravity of Earth and so we know quite a bit about being in lower gravity affects a person's body, from studying astronauts and cosmonauts and other people that have been to space over the last half century or so. So, we know that one of the things that happens is that it affects the muscles and bones. So if you're living in a weightless environment, like if you're on the International Space Station, well, you know, especially if you're there for a long time you're going to have to do a lot of exercise because, if you don't, your muscles are basically going to start to atrophy because they're not having to work against gravity and your bones are going to start to weaken as well. They actually lose bone density, they become more brittle and weaker. Astronauts have to do two hours a day of exercise to counteract that. So, I think one thing we could look at right away is how would one third gravity on Mars affect people who are living there for a long period of time. I mean, what if you are a baby and you're born on Mars into that one third gravity environment. How would your body develop? Actually we don't know, is the short answer because nobody has done that exact study but we can kind of extrapolate from what we know about zero g, right, the weightlessness environment of low earth orbit and say that it does affect the formation of bones and muscles. Actually I think that would be a really potent force for natural selection to act on. I think that you would start to, in just a few generations, potentially start to see changes in the skeletal structure and the musculature of people living on Mars. You might expect that they might become sort of leaner, they don't have to work as hard against gravity in order to build muscle. Their bones might become thinner, more brittle. Natural selection would basically allow that because there wouldn't necessarily be any negative consequences for that if you're living in a one third gravity environment. The problem for astronauts happens not when they're in space, but when they come back to Earth. And so that's another thing we can talk about is, could people who are living… you know, who are born on Mars, could they come back to Earth? I think there is a number of reasons why the answer might be no. We need to think about that. The changes to the skeletal structure and the muscles and our build is one potential change that could happen but another big difference between Mars and Earth is that Mars doesn't have the magnetic field that we have here on Earth that protects us. So recently there is amazing auroras, these amazing northern lights that many people, certainly here in North America and in other regions including parts of Europe and Asia, they were able to see them in places where they don't normally and that is caused by the radiation from space and in this case it was the radiation from the Sun, from some solar flares. It was interacting with the Earth's magnetic field and that interaction of those particles from the Sun with our magnetic field is causing these amazing colours and dancing lights in the sky but it's a reminder that we're protected here on Earth by our magnetic field. Mars doesn't have that. So those same particles from the Sun, by the time

they made it to Mars, they are interacting with the surface of Mars in a way that, basically, if you were standing on the surface of Mars, you'd be getting the full brunt of that solar radiation. And there is another form of radiation in space and that's called galactic cosmic rays and those are thought to be the remnants of supernovas, of exploded stars that send particles out in all directions, it's just going everywhere in space and without a magnetic field, Mars is bombarded by that radiation. It only has a very thin atmosphere, so our atmosphere protects us to a certain extent as well. Mars' atmosphere is only a tiny fraction of ours and so no magnetosphere, very thin atmosphere, that means radiation is hitting the surface at nearly full strength. So, we know radiation is harmful. This is the reason why you have to wear a little lead apron when you go to get an X-ray right? Radiation can cause damage to your DNA. So we would need to have some protection from the radiation of space if you were standing on the surface of Mars, you would need a space suit but even that wouldn't be enough. So a lot of the designs for Martian settlements, Martian habitats, involve some kind of radiation barrier, some protection from that radiation that might involve living underground, that's one model, or having some kind of a very thick barrier that protects from radiation. Even with that, you know, people are going to want to go to the surface, people are going to want to not just be underground in bunkers all the time, at least that... I don't want to go to Mars if I have to stay underground all the time so I think people are still going to be exposed to more radiation there than they are here, even with those protections. Then we can ask what is that going to do to a person? Well, one thing is it probably will make cancer rates much higher on Mars and that's going to be a real challenge. I think that's going to be one of the major issues with people living on Mars, but for people who don't get cancer, what radiation does is it causes mutations. It causes changes to the DNA sequence that are basically the body's instruction manual and with those mutations, actually, are the raw material that natural selection uses to create adaptation. So, one way to think about that is actually that higher radiation, if it's not just, you know, lethal, it will actually increase the mutation rate and cause there to be more genetic variation in the population of people living on Mars than we have in the population of people living on Earth. That basically means that there is more potential for adaptation, so more ability of natural selection to kind of tweak the human body to help it to adapt to the conditions on Mars. So that's kind of an interesting twist, I think, to the way that we often think about the impacts of radiation. We do know that there are things here on Earth that do help with radiation protection. One of them is the pigments in our skin. So, the amount of melanin that we have in our skin, and there's a couple of different types of melanin but one of them is called eumelanin. That eumelanin is what produces dark colouration in human skin and it's the same in many other species and the more eumelanin you have in your skin the more natural protection from certain types of radiation that you have. So you might imagine that natural selection would favour more eumelanin production in people living on Mars if it gave some protection from radiation. So perhaps darker coloured skin is something that you might expect to be going along with adaptation to conditions on Mars or maybe people on Mars will evolve new types of radiation protection. Maybe new pigments, new skin colours. Maybe that's how we will get our little green men from science fiction, living on Mars. Maybe they'll develop green or orange or who knows what colour, you know, blue skin? Ultimately we can't really use evolution to make specific predictions and say this is what we think will happen. We can just talk about what are

the range of possibilities and what precedents do we have for that type of change from evolution that's happened here on Earth.

I: That's a fascinating point you made about how natural selection might occur faster on Mars because of the increase in radiation mutations. Just going on from that, what kind of timescale are we talking here? Because obviously natural selection generally occurs over generations and generations and can take centuries and thousands of years to make any sort of discernible change. What kind of time frame are we thinking on Mars that we will start to notice these big changes?

R: You're right, so evolutionary change by definition is change over generations. So, if you or I went to Mars, even if we had some changes to our body, you know, astronauts often grow a little taller when they don't have gravity pushing down on them, we wouldn't consider that to be an evolutionary change. But if we have children there and they're a little different from us and their children are a little different from them, you know, gradually those changes can be considered evolutionary changes and so yeah, I think you're right that this is not going to happen within a few decades. It might not even happen within a few centuries. Evolution typically is a pretty slow process. Part of it depends on how long does it take for a species to go from one generation to the next. In humans, we usually consider our generation time to be about 25 years. Obviously it varies a little bit but that means in a century you've only had about four generations. So that's not a lot of time for evolution to take place. So I think we should be thinking about centuries or longer. However, I do think there are various reasons to believe that evolution would take place faster on Mars than it does here on Earth and one of those reasons is what we were just talking about, the fact that radiation would cause the mutation rate to increase on Mars and that gives you more genetic options for natural selection to choose from. But it's also possible that the generation time will get shorter. We talked about how cancer is likely to be a big problem. I think life on Mars is going to be hard. It's going to be a harsh environment, not just cancer, but other challenges of living there in this remote, desolate, harsh environment. People living out on the frontier often didn't live long lives and I think its reasonable to expect that lifespans on Mars would be shorter than they typically are on Earth. That could mean that generation time is actually shorter, so that's another reason why natural selection might take place faster. But the third reason is that we know that natural selection can be stronger or weaker and that's one of the other major factors that influences how rapidly species evolve. If natural selection is very strong, then they evolve quicker and what that means, strong natural selection means like, if you have any slight genetic difference, if that difference gives you an advantage in survival and reproduction, an advantage over the others in your population that don't have that particular trait, well that means that's stronger natural selection. Typically we see stronger natural selection in places where the environment is very different, very different from what it used to be or very different from wherever those individuals came from. Of course, we know the environment on Mars is radically different from that on Earth. So I think you would have very very strong natural selection. Any individual that happened to be born with mutation that say, gave them some radiation protection, just to give one example. That might really increase their lifespan significantly, it might make it much more likely that they have children, they might have many more children and that means that trait

gets passed to the next generation and can rapidly spread through the population. So I think it will happen much faster on Mars than it happens on Earth.

I: Wow, it's an intriguing prospect. How profound do you think these changes will become? Over the course of centuries or even millennia, is it possible that there could be a separate species of human living on Mars?

R: Yeah, this is an idea that really intrigues me. To answer that question we have to ask, well what does it mean to become a new species? How do new species evolve? When do we consider a species to have come into existence? There's a lot of different ways that biologists think about this but one of the most common ways is to say okay, it's a new species if those individuals can no longer interbreed with the other individuals. So in other words, if humans going to Mars can no longer have children with people from Earth, that might be one way that we could say okay, they have evolved into a new species. So, what would that take to happen? How long would that take or what would be involved? This is another way where I think it could actually happen much faster than we typically are used to here on Earth and I will give you one scenario for it, that I think is plausible. And that is, if we think about what happens to our immune system. Our immune system evolved here on Earth to be able to defend us from the kinds of things that cause infectious diseases here on Earth. Bacteria, viruses, etc. Well, if we go to Mars, the only infectious diseases are going to be the ones that we take with us. As far as we know there is no microbial life on Mars. If there is then there's a lot of other things we need to talk about but as far as we know, there's not, so the only germs we have to worry about are the things that we take with us. Now that's going to only be a small subset of what we normally encounter, the microbes we normally encounter here on Earth and I think it's actually quite reasonable to expect that certain diseases will just get wiped out from a settlement on Mars right. We might not have to worry about things like, you know, tuberculosis or smallpox or things that are still present here on Earth but only in isolated populations and only during certain time periods. Diseases like malaria that are spread by mosquitos, hopefully we will be careful and not bring any mosquitos with us to Mars. I'm certainly optimistic about that. So, that means that those diseases are no longer a problem. So, what happens to our immune system in that case? If you're a person living on Mars, if you're a baby born on Mars, and you grow up in an environment where you're very rarely, if ever, challenged with any infectious diseases, certainly those that are found on Earth, well maybe your immune system starts to atrophy or maybe it isn't able to defend itself against certain types of germs. So, that would mean that it would be very difficult for that individual to ever come back to Earth because just common microbes that we interact with all the time that aren't a threat for us might be deadly to a person on Mars. Likewise, if a person from Earth travelled to Mars, they might have some bacteria or something on them that would just be a deadly threat to a Martian and so what you might end up having to do is to keep people from Earth and people from Mars isolated from one another, even if they were together in the same place, you wouldn't want them to be in close proximity and to interact. So, you know, that is one way in which you could rapidly get this kind of separation of people from Mars and people from Earth. Any mutations that pop up in the Martian population aren't going to be spread to the Earth population if people never come together, they can't have kids together, they're not going to share their genes. So you could rapidly get this accumulation of genetic differences in these two populations if it's necessary to keep them

apart just in order to keep them alive. So, in that scenario I think you could actually pretty rapidly within maybe only a few generations, you could start to see some of these genetic differences accumulate and before long, you might end up with two different species that are no longer able to interbreed. You've got people from Earth and you've got Martians.

I: Obviously it's a fascinating idea but it's also kind of concerning in a way. Could it almost create a two-tiered humanity, a very divided humanity? It makes you wonder how we will navigate that when this is happening, also from a social and cultural side and political side, I wonder how that will pan out?

R: Absolutely. I think these are actually really important questions. It's one of the reasons I'm working on this book idea because in my view, I don't know that people have really thought this through as much as they need to. So, there have been a lot of different ideas. A lot of them come originally from science fiction, living in space, building cities on Mars and other planets, but increasingly those are more mainstream ideas that are being discussed in the scientific community and my concern is that a lot of the focus often is on how do we get people there, how do we build these kinds of habitats, settlements, cities, whatever you want to call them. And I think we need to also be thinking about the biological consequences of space settlement if we are going to be taking this seriously as an idea. I think you're absolutely right that there are all sorts of ethical, moral, and other dilemmas that come up. Is it okay for a baby to be born on another planet that is unable to ever return to Earth? I think that's a serious ethical question. Then yeah, you're right, like the culture, the politics, all of those things that we know are a part of what it means to be human, they're all going to be at play and again, science fiction authors have explored these ideas extensively and I think maybe instructively in some cases, maybe we need to look at some of what other people have thought about in terms of the possibilities for what could happen. Ultimately I think we need more information before it would be reasonable to actually start down that path of creating a place where people aren't just going to visit for a while but where they're actually going to live out their lives.

I: What's your take on it? I know a lot of scientists and people who are pushing for us to put humans on Mars such as Elom Musk, they often say it's a necessity that we become a multi-planetary species, it's not a matter of if and how we do it, we need to do it. What's your take on that? How do you perceive that?

R: I think it really depends on what time frame you're talking about. I do think it's true that if you are going to consider the very long-term future of our species that having all of your eggs in one planetary basket, so to speak, is not a recipe for success. At the end of the day, something here on Earth eventually will threaten our existence, whether it's a super volcano eruption or whether it's another asteroid impact like the one that caused the extinction of the dinosaurs, or whether its something that we do ourselves, there's a lot of things that could threaten our future here on Earth and the longer we're only here, the more likely those threats are to come to pass. So, I think that yes, ultimately, our long-term future may in fact depend on our ability spread out from Earth and onto other planets like Mars but I think we have to also recognise that right now, we're not quite ready for that. There are still fundamental questions that we don't yet know the answers to in order for us to reasonably, responsibly, ethically start down that path towards settlement of Mars. So, I am all in favour of doing the research. I think we

need answers to these questions, they are important. We are talking about the long-term future of maybe not only our species but life on Earth more generally. We need to know, for example, is human reproduction in the Martian environment possible? How would we be affected by living in that one third gravity environment and that high radiation environment? We need to know for sure, is there life on Mars other than what we bring with us? Once we have answers to those questions I think it will be an exciting future to start building settlements and inviting people who choose to go there to live there, but I just don't think we are ready quite yet.

I: Just one point there which I would like to bring up as a last question. You mentioned how the human colonisation of Mars, we might also bring other species along with us. Obviously there will be countless microbes, fungi, bacteria. We might also bring, cats, dogs, who knows. Have you ever thought how the human colonisation of Mars might impact other species in their evolution?

R: Absolutely. I mean, anything that we bring with us, any living thing that we take to Mars is going to evolve as well. As I said before, there is no way to turn off evolution and of course, the harsh environment of Mars is going to affect us and it's going to affect other species as well. So yes, of course, we should expect and we should think about what that means, for which species we choose and sort of how we allow them to adapt to those conditions. One thing to think about is obviously we would be competing for resources, like air and water and food with any other animals that we bring with us, so the idea of bringing livestock. I don't know that putting a cow on a rocket and taking it to Mars makes a whole lot of sense for a lot of reasons, not least of which is then you're competing with it for air and water and food. So, there's a lot of reasons why being vegetarian or even vegan might make the most sense for people who are living in a Martian settlement. But even the plants that we bring with us. We depend ultimately on plants as the base of the food webs here on Earth and so if we're going to have a stable existence there where we're living off the land, we're going to have to grow our own food. So, crops on Mars? Absolutely, that's a necessity in my view. How do those crops change? Well, we have a long history, about ten thousand years, of basically breeding crops to suit our needs so we have a good idea of how to do that. Now of course, we have new technologies, genetic engineering for example, that is one way that we can try to modify those crops to allow them to be better suited, better adapted to the Martian environment. So, I would expect that would be an element of any kind of Martian farming, any kind of Martian agricultural system, whether it applies to plants only or to perhaps to animals that we bring. I would say no to cows and pigs but yes, maybe to other kinds of animal livestock, like, say, insects. Maybe the Martian farms of the future look more like cricket farms than they do like cattle ranges.

I: Yeah, certainly. Well we have some very interesting but complicated times ahead of us. Can't wait to see how it will all pan out. It's been great talking to you. Thank you very much for chatting to me.

R: Thanks for having me, it's been fun.

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