# “ESA Scientific Exploration of the Moon" by Francesca McDonald

**Abstract:** [https://meetingorganizer.copernicus.org/EPSC2021/session/41793](https://meetingorganizer.copernicus.org/EPSC2021/sessionprogramme)

**Video link:** <https://vimeo.com/showcase/8853994/video/610622982>

**Plain language summary**

In this talk Francesca McDonald, Moon Exploration Scientist at the European Space Agency (ESA), explains how ESA is working with international partners from the USA, Russia, Japan, India and China to prepare for scientific exploration of the Moon between now and the early 2030s.

ESA’s strategy for science on the Moon is structured around seven ‘campaigns’ that tackle the main unanswered scientific questions about Earth’s natural satellite, and the technological challenges that need to be overcome for humans to live and work on the Moon.

The campaigns include: a detailed investigation of the lunar poles, where water ice is trapped and protected from the Sun in deeply shadowed craters; plans to monitor dust and charged particles that surround the Moon; geological measurements to study the surface and to try to understand what’s happening deep inside the Moon; biological and technological studies to pave the way for life support; and using the unique environment of the Moon for physics experiments to study the early universe and test the theory of relativity.

Technology demonstrator projects currently being built and tested include a ‘can-opener’ for carefully extracting and preserving samples of lunar rock that have remained sealed since they were collected by the Apollo astronauts 50 years ago, and an experimental set-up for extracting oxygen and water from lunar soil.

With NASA’s [Volatiles Investigating Polar Exploration Rover](https://www.nasa.gov/viper/) (VIPER) and the Russian Luna-27 mission, carrying ESA’s [PROSPECT](https://exploration.esa.int/web/moon/-/59102-about-prospect) instrument package, and NASA’s [Artemis crewed mission](https://www.nasa.gov/content/humans-on-the-moon/index.html) all due to land on the Moon by the mid-2020s, the next few years will see renewed excitement in lunar exploration.

**Full Transcript**

**Sebastien Besse:** Good morning, everybody. So, we're going to slowly start the day, travelling relatively far. We're going to go to the Moon and hear bit about what's happening in the Solar System. I'm going to wait a few seconds more Francesca, if you don't mind, because I have the experience has been that it takes a bit of time for everybody to catch up and join the meeting, so we'll see how that goes. I see the participant list is growing so we're going to keep that a bit going.

So I see a lot of familiar names, that's really good news, a lot of people not really Moon people as far as I can see, so that's a good thing. So, we're going to hear from Francesca for the next 20 minutes, we have a 30 minutes block. We're going to be, we're going to have some time to discuss that. And then we're going to have some time for questions so don't hesitate to put your questions in the chat. I'm going to monitor that and get to you, Francesca with all those questions.

And normal business, mute yourself. Be, you can disagree but be respectful, as usual. I'm going to give you a quick summary of Francesca, which is she's currently in a role, Moon Exploration Scientist at ESA, and is really trying to as best as she can to collect all the ideas for everybody to just drive the visions of the community, with the help of ESA, and try to make possible all these opportunities that exist with all the partners we have around.

And before that Francesca has been doing a lot of work in terms of dating techniques with with particularly argon isotopes on the Earth, and on the Moon as well. And so that has been really interesting. She did a PhD on characterising the argon dating of the mantle derived rocks from the Moon and the Earth to try to understand the balance between the two. And so, Francesca, I'm going to give you the floor, please share your screen and tell us everything that is going on on the Moon.

**Francesca McDonald:** Thank you, Sebastian. See if my screen's working first.

**Sebastien Besse:** That's all good. Great for the Moon.

**Francesca McDonald:** Okay. So, thank you for inviting me here. I'm pleased to share what's happening at ESA. There's a lot going on, hopefully I get through it all, so I apologise if I have to speed up at some point.

But yeah, there's a lot happening, so it's an exciting time and what do we want to achieve by going to the Moon? Well, first of all, you know we want to understand how to live and work in the lunar environment, to identify potential resources and establish how we might use them responsibly. Establish the Moon as a sustained platform for scientific research. It's a unique environment for a science laboratory. In the process, we can create roles for European industry and commercial opportunities and whilst we're doing it, we're building international partnerships in the near and long term, and there's lots of lessons learned and capabilities that we can build for onward exploration for Mars and the rest of the Solar System.

And the ways we're piecing through this at ESA at the moment, we have a strategy for science at the Moon. And we also have a space resources strategy and these can both be found available online. Here's a little image of the front covers there. Within the strategy for science at the Moon, we have seven science campaigns, and I'm going to talk you through these campaigns in the context of this talk, and what's coming up as well is a more overarching science strategy for the Human and Robotic Exploration Directorate at ESA, and this will underpin into a big overall strategy of architecture and technology as well as the science.

So, within the strategy for science of the Moon that we are working from, we're looking towards the kind of 2030s vision. So, in the early 2020s we're looking for options with delivery through opportunity activities and partners, and we are already securing flights for some of these opportunities and talking to new international partnerships. Mid 2020s we're going to look more into delivering on robotic missions using perhaps the commercial lander delivery options, and there are many of these under investigation, and we know it's becoming a big area in the commercial industry. And then towards late 2020s and early 30s this is where ESA is looking at these kind of managed developments, perhaps using something about European Lunar Large Logistic Lander which is in development as a concept, and this would have the capability to deliver human and robotic lunar scenario, whether it's in the form of cargo or science or technology to support exploration such as through ideas like Artemis, and there's discussions with NASA ongoing there.

So, as I said, we've got a run of campaigns, and this first one is analysis of new lunar samples. So, although there's been a decision at ESA programmatically to not advanced an ESA-led sample return mission at the moment, it does not mean we're not going to be heavily involved. There's discussions with NASA regarding involvement through Artemis and how we can support this. And we're also contributing already to initiatives such as the Apollo Next Generation Sample Analysis and I'll explain on this little bit more in the next slide, and other ways that we can help towards assisting and optimising crude surface sampling activities in the future.

So here are the preparatory activities that we're undertaking as part of the Apollo Next Generation Sample Analysis programme. And this programme's a US-led programme made up of an international consortium. And it's to examine some pristine specially curated samples from the Apollo collection. These samples have remained sealed since they were collected, 50 years ago. The consortium at ESA is involved in particularly looking at Apollo 17 drive tube samples. And this was collected from Station 3 where this white arrow is pointing on the map here from this landslip region that's come down from that South Massiff area there. You can sort of see that lighter deposit, that's the landslip. And by opening this sample, we want to explore the lunar volatile reservoirs and cycles, see what may have triggered the dynamics of that lunar landslide and just overall learn more about future containment of samples for future return missions, whether it's the Moon or Mars.

Because this sample has been specially curated in a vacuum sample container, we want to explore how to carefully open this container and extract possibly the loosely bound volatiles within there, and then also make sure that we preserve the solid material for future analysis.

So, the core part that ESA's been involved in is perhaps in designing what we're calling a 'can opener' that's fit for Apollo. So, at the moment, there's no obvious valve of how to extract the gas in a controlled manner. And so ESA's helped to design and deliver a solution for the controlled gas piercing tool that can interface the CSVC into an ultra-high vacuum system to collect aliquots of the gas for analysis. Now there's lots of challenges between making sure you preserve the pristinity of the regolith there, avoiding contaminating the gases that you want to target and not inducing isotopic fractionation, and also the engineering challenges around ultra-high vacuum conditions. So we had to derive piercing forces. There's a little set up in the left image there. And then there's a CAD image of the design we developed and on the right there is what this piercing tool looks like. It's now being built and we're starting to do the testing before this will go to NASA Johnson Space Center at the end of the year.

Otherwise, we're helping set up preparing how you can support a human sample analysis mission, and there's work on an electronic fuel book and this is a whole system that really looks at harmonising how you could use handheld mineral identification systems that can feed back to the backroom science area to really understand real time how you can identify certain minerals and optimise in the samples you collect. And this is an ongoing area, with lots of machine learning and analogue field testing, which really

showed the benefits in optimising the science and the geology we can achieve in the field.

Moving on to Campaign 2 - this is where we can really look at characterising a polar region, focusing on volatiles. There's lots of development here, it stems from the polar PROSPECT. This is already development that's going on in partnership with Roscosmos. And this looks at a drilling into a metre below a polar region, extracting samples there and passing it to a suite of scientific instruments to warm them up and release the gas to do vol gas analysis and this is really tell you about the volatile history of the Moon, but as well as understanding the potential of these volatiles as a resource.

Now, there's lots of spin outs and elements of this package that are now being developed for future flight with international partners including NASA and JAXA and ISRO, and we've even got some very early instruments for some those first flights from the CLPS programme. In the bottom right here you'll see the exosphere mass spectrometer which is an element from the PROSPECT family, and that's an ion track mass spectrometer that's really going to understand sort of the water cycle behaviour by analysing the exosphere there and that's in partnership with Goddard Space Flight Center. But we have other areas that we're going to explore. Looking on to a larger mission scale, we're starting to do with an early study looking at a long duration two-year mobile polar prospecting mission that can really build on the PROSPECT and other volatile missions, such as VIPER.

This will help to rebuild high resolution maps on a bit more spatial scale, as well as informing on volatile sources, evolution, migration and sinks. That can really extend the global view of lunar lithologies to expand beyond the Apollo regions that have been extensively explored to more polar areas.

We've done a study in the context of this European Large Logistic Lander originally but everything we’re studying is looking at different interfacing options and modularity for different lander capabilities. The particular reference site for this study was the Shoemaker Faustini reference site at greater than 80 degrees latitude in South Pole region. And there's a study by Flahaut et al that show that there's variable ice stability depths between naught and one meter depth range, there's access to permanently shaded regions and then it's suspected there's an enhancement of water in this area about 125 parts per million. So the little dots you see there on that map looking across is where there's identified waypoints of scientific interest where a rovers or another mobile element could take a suite of instruments to do some extensive analysis. There's lots of challenges we're exploring as part of the study, in particular the extreme temperatures the long lunar nights to survive and low illumination elements.

Looking to Campaign 3, this is maybe how we would want to look at doing geological measurements to really understand the deep interior of the Moon and what this can tell us about planetary formation and the history of the Moon itself. At the moment in development we have the Moon-LIGHT laser retroreflector. And this is for flight to the Reiner-Gamma area on a NASA-CLPS delivery. And this can really help us understand the core mantle dissipation and understand the interior, but there's other activities coming up along with studies for a geophysics station.

And this can be then explored in the context of a wider geoscience mission, and all the studies we engage with topical teams from the science community in this case we a Lunar Geophysics Topical Team established.

For Campaign 4, we're looking at this kind of plasma and dust environment, the exosphere, what are the living conditions at the surface, and I've already mentioned about the exosphere mass spectrometer and that's not only been built but it's also been delivered for integration already to the Astrobotic first commercial mission in 2022, and we're in talks and discussions about Negative Ions at the Lunar Surface payload for Chang'e and we're just waiting for a Programme Board decision on that. But we also have payload package studies coming up that are due to kick off soon looking at a kind of weather station monitoring such as the surface environment. And we've also been consultation with another topical team to look out what plasma-exosphere-dust coupling can tell us about science and prepare for future exploration.

Campaign 5. It's all about the geology looking at the mineralogy, geochemistry, but a little bit into the shallow subsurface. So this is where again we have topical teams we can consult, and this will build a mission concept a little bit like the polar explorer one but but we're targeting different type of science and geology perhaps in a different area of the Moon. And we're looking to have preparations for that starting for an early study in January next year.

It's not only looking at the sort of history of the Moon itself on the surface but actually you can look at a biological campaign as well, and this is our Campaign 6, and how biological organisms, how they respond to this integrated lunar surface environment.

So we've already had a kickoff of a payload package study looking at exploring into this, we have a Lunar Biosciences Topical Team and then we're really looking to build this up and what would a lunar bioscience mission concept look like. And again we have studies upcoming for this as well. And those those biomission studies, they will be looking at how to utilise the Moon surface as a natural laboratory, in particular significantly advancing our understanding of biological systems and organisms in the integrated space environment and providing a step change in our ability to use biological systems to sustain a human presence on the Moon, and to investigate, ISRU applications, such as how biological systems can interact the lunar regolith itself, biomining or for future plant growth.

Campaign 7 is now looking at fundamental physics and astronomy on the Moon. Again the Moon can be used as a core platform to really explore some of these areas. So I already mentioned the MoonLIGHT laser retroreflector that can do numerous science explorations, other than just looking at the the internal workings of the Moon. It can also provide geodesy information and really test the gravitational situation as well, really testing the theory of relativity and really looking at some of these fundamental core physics that underpins a lot of our science understanding. And so, as well as this the the far side of the Moon is radio-quiet area and it's really interesting to use this then as a radio antenna platform. So there's a payload study for precursor radio antenna to really understand the environment and the feasibility of using this far side area of the Moon as a platform for astronomy. And there was a future view to build up to an Astrophysical Lunar Observatory and I'll explain a little bit more about a study that's already been conducted on this. And we've had consultation with another topical team there who really look at the astrophysics.

So this concept of an Astrophysics Lunar Observatory is ready to be, you know, exploring the Universe, probing the dark ages and cosmic dawn and opening up that last virtually unexplored low frequency regime; measurement of the global 21 centimetre emission.

So the mission drivers there are, as I said, the lunar radio-quiet far side, the shielding from the Earth's electromagnetic sources, and the study targeted a near equatorial reference site for maximum celestial sky coverage, looking at a four year mission lifetime, and two experiments were considered. The first was a radio interferometer telescope, which they call an 'imaging experiment', and this was really quite ambitious. It's a compact array of up to thousands - tens of thousands - of antennas so it's really demanding on systems but it's quite an exciting challenge to look at this, whether it's a small array of 1024 dipole antennas, or a large array in the order of 16,000 dipole antennas. And then there was the global detection experiment was also looked at, which could be composed of one or a few independent dipole antennas in isolation away from electromagnetic sources. So again this was initially explored in the context of using the European Large Logistic Lander as a platform, as a dedicated landing system. And there's lots of challenges about exact placement, and there's going to be follow up studies on this as they will be with all these other studies that I mention in here. Now it's not just the science for the Moon that we were looking at. All captured within that science is how can we have the strategy for space resources as well, and it's really how can we establish the Moon as perhaps an area that we can explore for the resource potential in space. So, the strategy for space resources, it starts with saying we need to establish the resource potential across the lunar surface. That's whether you're looking at a polar region, the regolith, or volcanic deposits that perhaps become derived from the mantle. Now we already have in development the PROSPECT family suite, as I was saying, and then there's other crossover lunar science activities with Polar Explorer and perhaps geology missions that can really start building up the global picture of what, not only the science of the lunar surface looks like, but if they are the resource potential there. The next thing is to be able to mature and demonstrate technologies which have then key to the value chain for space resources and have terrestrial benefits as well. So in preparation, we do have these technology activities being informed by these science studies that have been mentioning.

And then we have ongoing investments in a new European Space Resources Innovation Centre based in Luxembourg. Beyond that you want to demonstrate end-to-end in-situ production of a product from lunar materials on the Moon. And again, this is where we have another study ongoing, it's actually reached Phase B1 now, an ISRU demonstrator, and this demonstration mission actually starts with emphasis on oxygen or water production as a first resource. But there are lots of other resources potentially available on the Moon, even the regolith itself as a building material. And then beyond that, you can demonstrate all the activity, but if there's no demand or no market for it, there's not a lot you can do with that. So the next stage will be to actually establish ISRU, that's in-situ resource utilisation, as part of the international space exploration architecture and to foster demand locally for produced projects. So this is where we start looking to, to the longer-term future studies of scaling up these demonstration lessons, and we're looking into perhaps the first lunar surface pilot plant study to see how this would scale and how this may foster demand for both local production, perhaps with benefits on the Earth in the future.

Part of that as well is ground based research that is going on and there's the oxygen extraction from regolith is being honed in, so that we have a cell set up at the ESCTEC site here Netherlands and it's based on the Fray-Farthing-Chen Cambridge process, which uses molten salt electrolysis to extract oxygen directly from the regolith itself. In the top right now we have an image showing the setup that that we have to use this. And the research goals that are being attained here are to better understand the reduction mechanism for individual minerals within the lunar soil itself, and to optimse the oxygen extraction process from real lunar soils. It's already been demonstrated with stimulant, but we now have recently been allocated from the Johnson Space Center some real samples to hone this technique. Prior to that we're looking at what are the different salt solution balances. There's an image of Beth and Alexandra in the bottom right hand corner, they're working away.

And it's not only the extraction of the oxygen that can be beneficial here, you actually have a by-product, it's a metal alloy, that image there is the unreduced regolith on the left and then on the right you have the resulting metal alloy, and it's understanding how this can be used for potential additive manufacturing. So we're going to look at different types of Apollo soil from both the highland and from the volcanic mare region and those that have been exposed for a long time at the surface and those that may have been buried a little bit below the surface and see this has an effect on the process. So just to give you a summary of those studies, there was a lot of information that I presented out there.

And so these are all going to be producing future opportunities for European scientists and industry, so we talked about a lot of mission concept themes. If you look on the right there, there's Polar Explorer and looking at water ice and volatile prospecting, we've got the Astrophysical Lunar Observatory, coming up biosciences mission exposing diverse biological samples, and then geological exploration of new terrains and lithologies. And as part of the study, and coming from these, is the payload packages there - the instruments suites that would support these and that's on the left here. We're looking at the biosciences exposure facility, the low frequency pre-cursor radio antennae, a geophysical station, and this would need to be stand-alone with its autonomous survival pack be doing meaningful measurements, so perhaps like a five year plus period and with a view to sort of internet connecting and making global network with international partners. Similarly, for an exosphere and environment weather station, we want to know what this instrument would look like and how we could perhaps build up a global network.

And then geological analytical package and water ice and volatile prospecting packages. These would be complimentary packages that would be modular and be on board mobile units such as a rover or a hopper to do exploration of the local geology. But this that we're taking these mission concept themes and payload packages they can address the campaigns and goals that are in the ESA strategy for the science at the Moon and the resources strategy, but they also build on existing studies and experience within ESA. For example, there was previously the Lunar Volatiles Prospect study, the Lunar Dust and Exosphere Plasma Package. There's an Automated Planetary Payload System, this was looking at a geophysics station with an autonomous package. It wasn't looking perhaps at all the regions on the Moon. And we have a wealth of experience from the ISS, particularly when it comes to the biological and life sciences. We've already been doing studies on the Gateway of how you might look at bioscience exposure facilities and then expanding this to the Moon as well is a key next step for the future.

But the way that this is being put together, it's looking to create Member State roles and attractive potential roles for international partners and national contributions. We're looking at modular, flexible, divisible elements that are appropriately sized. And just on the right there is a first little CAD mock up of perhaps what the EL3 lander would look like if you were to have a technology and science instruments suite on there and I put a little astronaut there for scale because it could also be provide cargo to support Artemis as well for science there. So I'll leave that as my summary slide and I, yeah, I welcome any questions but appreciate as a lot of information.

**Sebastien Besse:** Thank you very much Francesca, that's a lot of things going on. I hope you have sufficient time to follow all of these. And I'll be monitoring the questions on the box in Zoom so don't use the chat, use this Q&A system if you want. Nigel Mason is asking your first question. What role do you see for private sector in lunar exploration and exploitation, and how would ESA collaborate with the private sector.

**Francesca McDonald:** Yeah, these are all very good question. So there's going to be how these, these, these roles, how these come up so there's, as I said on the first slide we're looking at the different types of opportunities that are out there, that's private, commercial, international partners and they'll be different opportunities along the way, but tomorrow we will have a panel interview with the the agencies and there'll be more of the programmatic overview where I would probably directly to ask those questions more there. I very much focus on the science part of it.

**Sebastien Besse:** A follow up question from the streaming page on Vimeo from Colin Wilson. Thanks for your talk, Francesca. What routes are there for scientists who wants to get involved in these programmes? Are these opportunities to join... Are there opportunities to join topical teams or study teams, or even more topical teams in the near future?

**Francesca McDonald:** Yeah, absolutely. So we had a run of workshops at the end of last year, after an open call for informational on perhaps how would you, what would you do at the lunar surface, perhaps utilising EL3, and we were, we had an overwhelming response, brilliant ideas from the science community and the technology community there. And this is all being reflected throughout the study concepts that we're building opportunities. Here's the ways that people can be involved in topical teams, is there's a constantly open announcement of opportunity online on the ESA site for topical teams, you just need to submit an idea and a proposal and then there's an authorisation process that we go through, and we consider all applications through a peer review process with working groups.

And there's… There'll be future workshops get involved but all of these payload packages, they come with invites to tender get released, and we find that some of the best teams respond to those that are combination of science and academia and industry, not just industry.

And as these concepts develop and they get presented to the Ministerial and go through selection processes, there'll be future announcements of opportunities. But we will advertise workshops, please do propose topical teams if you, if you are interested and yeah look out for future opportunities and announcements that makes them from these early studies.

**Sebastien Besse:** So we have a bit more time if you have any questions, still do not hesitate. Francesca will be very happy to answer. I have one myself which I picked, one of the things that I found really exciting from your slides when you started to mention about the first planned studies. And I was just like - do you have any timeline for that because you didn't put any dates around that?

**Francesca McDonald:** The first planned studies? Yeah. That'd be, yeah. So, um yeah I did have dates there but I took them out so that people didn't get sort of caught up. But for a lot of the these studies they are already in progress at the CDF, so at the Current Design Facility study where we do them internally with all the systems engineers with the science input there. Some of these are now going to spin out into pre Phase A studies, so this will all be happening from now onwards throughout 2022, to be able to inform as best as we can Ministerial at the end of 2022, and then decisions will be made and which ones will go forward and be progressed more. But then something like the European Large Logistic Lander, this isn't just a one shot mission This is designed to have a cadence of flights perhaps on every three, three year scale. So it can be a case of many of these mission concepts can be developed for future application moving forward.

**Sebastien Besse:** Thank you for that. It sounds quite exciting. And one other thing you you mentioned at the beginning, which is actually a good, a good understanding for us in the community to see where this is going, where ESA will not move forward in terms of leading sample return missions or these kind of activities. But in terms of the facilities on Earth themselves, is there any thing that ESA wants to support or is it up to the community and to national countries to do this. Can you tell us a bit more on that topic.

**Francesca McDonald:** Yeah, so, ESA is already involved with Mars Sample Return and the Sample Fetch Rover, so there there needs to be some form of planning of what happens when you get these samples back. And there's already close talks with NASA around Artemis as well because there's a huge sample science community in Europe. There's about 30% of all of the allocated samples from the Apollo collection have gone to PIs within Europe, there's a really strong sample science community there, and this is recognised. So there are discussions about how would we prepare in Europe for receiving samples. As we said there's no ESA-led sample return at the moment but it is heavily involved. There is early exploration into what would architecture look like, looking at perhaps double-walled insulators that would honour planetary protection for the Mars case and then they'll also be learning from the lunar case and how it can be adapted for the lunar case, particularly with expecting more volatile-rich samples to be coming back from these polar regions, then this is a next step to be learning and preparing for in terms of receiving and curation and sample handling on Earth before as part of the preparation for these upcoming missions. So ESA is involved in some of this early planning, but it is early days yet.

And you just opened the door for one of my last questions which is very open, is, like, we have all of these good strategy for the 20s with a lot of different type of missions and project and studies. I won't use the term contingency, but what is the plan if things goes differently. Because I would expect the first missions are going to bring new questions, or as you mentioned, maybe they will be richer in volatiles than we expected. Are you guys looking into, like, how do we change that plan in 2024 because everything we thought would be different, for the best or the worst.

Yeah, absolutely, as you say there's a lot going to happen on the Moon before some of this goes into action. But that's great, and I think we can build, we can learn and that can actually go and inform and that's very much at the forefront of these studies. How can we have this modular and adaptive approach to respond. In particular, once we get these... the information back from VIPER and PROSPECT, they can really help and inform with where are the best target sites to go to for the information? What is it that you really want to hone in on? What have we learned? Is there water there at all? If that's the case, then what else can we learn when we go there in terms of perhaps volatiles or understanding the properties of the rocks that we have we have in that region? So this has all been expected but it's building up from the information we have. So you start with a more of a point analysis, a detailed point analysis from PROSPECT, a slightly broader view from perhaps VIPER and then you have this larger Polar Explorer campaign that can really build on that view.

And that's the kind of contingency that we're building into this. You start with a low frequency radio antennae that can sort of really understand and gauge how does these antennae interact with the topography with the lunar surface environment, and then you can build up that concept into the the vision of that Astrophysical Lunar Observatory. And it's working internationally to build up networks with international partners as well. So it's not all set in stone. It's responsive and learning too. What are the new science questions that crop up from the missions that go before as well.

**Sebastien Besse:** Great, excellent. Thank you very much, Francesca, for your time and for this great summary.