House of Commons

Science, Innovation and Technology

Oral evidence: UK astronomy, HC 329

Wednesday 8 May 2024

Ordered by the House of Commons to be published on 8 May 2024.

Watch the meeting

Members present: Greg Clark (Chair); Dawn Butler; Dr James Davies; Katherine Fletcher; Rebecca Long Bailey; Stephen Metcalfe; Carol Monaghan; Graham Stringer.

Questions 207 - 266

Witnesses

I: Dr Jessica Dempsey, Director, ASTRON (The Netherlands Institute for Radio Astronomy); and Professor Dr Michael Kramer, Director and Scientific member, Max Planck Institute for Radio Astronomy.

II: Professor Nicolas Thomas, Professor, Space Research & Planetary Sciences, Physics Institute, Universität Bern; and Mr Gabriele Cremonese, Senior Technologist, Istituto Nazionale di Astrofisica (INAF) and Osservatorio Astronomico di Padova (OAPD).

Examination of witnesses

Witnesses: Dr Jessica Dempsey and Professor Dr Michael Kramer.

Q207 **Chair:** The Science, Innovation and Technology Committee continues its inquiry into UK astronomy. We are pleased to have four international perspectives to inform our inquiry.

I welcome our first pair of witnesses. Dr Jessica Dempsey has been director of ASTRON, the Netherlands Institute for Radio Astronomy. She was previously deputy director of the East Asian Observatory in Hawaii.

Joining her virtually is Professor Dr Michael Kramer, who has been director and scientific member at the Max Planck Institute for Radio Astronomy in Bonn since 2009, as well as professor of astrophysics at the University of Manchester. He was president of the German Astronomical Society and chair of the Council of German Observatories. He was awarded the Herschel medal of the Royal Astronomical Society in the UK.

We are interested in your perspective on how different countries compare on the state of astronomy and its funding in the UK. Dr Dempsey, given your experience will you give a flavour of how things are done in the UK compared with the Netherlands and other countries with which you are familiar?

Dr Dempsey: I am happy to do so. I am not unique, but I worked for the STFC in the UK. I was one of the original four members of the foundation that built the James Maxwell telescope in Hawaii. I can compare and contrast my experience of that with the Australian systems and over 10 years in the United States astronomy landscape. I have had two years of intense experience in the Netherlands.

I shall make two points of note that might be pertinent to you. The United States system is largely co-ordinated on one important thing. It co-ordinates its priorities set over its decadal plan. The decadal plan is the astronomy bible for the future of United States astronomy and is an important part of its system.

It is a very competitive system. It is survival of the fittest in terms of the funding schemes, and it is starting to show cracks. The size and scale, in particular, of ground-based projects that the United States wants to do, and traditionally has done almost independently of collaborations with other countries, has meant that it needs, for example, to build a 30-metre optical telescope. There were two competing telescopes, and there is not enough funding for both at the moment. That is a bottleneck, exhibiting that the competitive approach that has been so successful up to now is hitting funding problems because the scale of the funds is even now surpassing the very large US funding system.

Q208 **Chair:** That is an interesting insight. Who resolves the competition? Who makes the decision?

Dr Dempsey: The primary funding agency, the National Science Foundation, has tried to step in to provide bridging funds. Otherwise, the funds are a consortium of competing university and private interests. At the moment, it is at the National Science Foundation to try to resolve, and it has said, "We can afford only one." It is becoming a crisis point in the system.

I see a shift going on there, and the comparison I would make right now is with the Netherlands. It is one of the smaller countries that I have worked for and within, yet it is a powerhouse. Across the scientific landscape it punches far above its weight, given its population and funding. That is in part because there is a very organised system of collaboration across the astronomy groups and institutes within the Netherlands, allowing them to co-ordinate their interests. They even sit down and decide who is going to go for the next funding round and they share it out equally. That tells funding agencies that astronomy has already got itself sorted out. The internal review system enables Dutch astronomy to be very successful compared with other STEM fields. It is almost seen as greedy on the landscape, simply because it is very organised and very successful as a result.

Q209 **Chair:** That is very interesting. To underline what you said, it is, as it were, self-co-ordinated. The different institutions agree among themselves and then approach funding agencies.

You gave an example from the United States. Is money wasted through that competition, or is there just disappointment among people preparing bids when one is chosen and one is disappointed, or is there money that might be available to science that is lost through that competitive process?

Dr Dempsey: That is a very good question. In some cases, it is a wasteful process. Unsuccessful projects reach quite advanced stages of development before being passed over. I do not think that that happens exclusively in the US system, but it encourages projects to make a lot of investment. Large optical telescopes are very mature in terms of the investment that has gone into them. If one should not go ahead, it is hundreds of millions of dollars lost.

Q210 **Chair:** You made a very interesting point that within STEM in the Netherlands astronomy is seen to do very well. Evidence we have taken from witnesses principally in the UK is that within the UK the opposite applies: within STEM, astronomy seems not to be participating to the degree that it might in the expansion of funding. Have you been aware of that, looking from the outside over to the UK?

Dr Dempsey: I was one of the very close and unfortunate participants in some of those decisions, one of them being when the UK stepped out of the collaboration for both UKIRT—the infrared telescope in Hawaii—and the JCMT itself. I am aware that some very difficult choices have had to be made across the UK landscape in changing funding systems.

It is interesting that here in the Netherlands a more co-ordinated approach perhaps avoids some of that waste. You might be able to look from the other side and ask, "Are they bold enough?" It is a conservative approach that has up until now worked very well.

The Australian system would be a closer comparator to the UK. Astronomy has traditionally underperformed on the funding landscape compared with other areas of STEM, but, arguably, the Square Kilometre Array would be a recent change.

Q211 **Chair:** Thank you. That is very interesting and very clear.

Professor Kramer, I put a similar question to you. You are with the Max Planck Institute in Germany, but you hold a chair at the University of Manchester, so you are clearly aware of the German and UK systems—and, I am sure, of others, as well. Will you give us your perspective on how things are organised, starting with Germany?

Professor Dr Kramer: Astronomy research in Germany is quite diverse in its structure. The largest number of institutions are at universities—about 40—but there are also about eight Max Planck Institutes, which get funding straight from the Max Planck Society, whereas universities apply for research council funding. We also have some Helmholtz and Leibniz Association institutes.

Funding could not be more diverse. At Max Planck, I have guaranteed funding until I retire, which is one of the reasons why I moved my main position to Germany. Universities have to apply for research council funding, but because of the diversity we get together every 10 years and try to come up with a common strategy. We had a meeting earlier this week in Potsdam, where we identified our main focus points and interests for the next 10 years or so. That diversity had a problem, in the sense that we did not have a common national voice, which sometimes is an advantage in big international projects like the SKA. We did not have the national voice of Germany speaking for the country as a whole.

We did not have a national centre, but we recently got funding via a restructuring of industry and the economy. In Saxony, for instance, we obtained €1.3 billion to create a national centre, with the aim of working closely with industry and using astronomy as a technology hub for a new innovation centre. That has been quite successful in making the case. There are very good examples where astronomy can point towards successes in that area.

The UK is quite different. You apply for STFC funding and smaller grants. It is more homogeneous. Both systems have advantages and disadvantages, but at Max Planck I enjoy long-term funding perspectives so I can do high-risk, high-gain projects without the risk of being shut down at some point.

Q212 **Chair:** Both of you mentioned 10-year horizons, and in your case potentially lifetime funding for your tenure. Ten years is common to both of you. The Square Kilometre Array is, in effect, funded for 10 years in the UK—if you bid for it, you make that commitment. Is that exceptional, Professor Kramer? In your experience, the 10-year perspective in the Netherlands and Germany is not practised in the UK.

Professor Dr Kramer: I think that 10 years is about the right timescale. Some really big projects take a long time. Some projects can be done faster. You need some flexibility along the way, so I do not think you should spend all the money on long-term projects. You want to move around and react to innovations and important discoveries. Ten years is a good point to look back at what happened to the plan in order to look forward to the next 10-year plan.

That helps to bring the community together—to focus and agree on what is interesting. That may be easier in the Netherlands than it is in a big country because everyone in the community knows one another very well, but Jessica can confirm that.

If you have a lot of different institutions, as in Germany and the US, the process brings together the people and makes them talk, co-ordinate and collaborate. That is one important aspect.

Chair: I will now turn to my colleagues, who have some questions.

Q213 **Carol Monaghan:** You talk about collaboration. I am interested in the networks in your countries—how the institutions work with academia, Government and industry. Do those groups have a common voice, or is everybody working independently?

Dr Dempsey: There is a level of independence in the academic research groups. It is important to have that diversity and engage across a host of different scientific topics, making sure that there is diversity among the people and those opportunities.

ASTRON is directly funded through the science Ministry and the major national funding agency of the Netherlands. They are critical structures, because we can be both an academic research institute and research and development. We are in charge of the major infrastructures and observatories, including the Square Kilometre Array and LOFAR, based in the Netherlands. That allows us to look a little longer term than perhaps the university research systems do and to be that one-stop place where we can speak and represent the broader academic community when engaging with large collaborations such as an international governmental organisation like the Square Kilometre Array or European research infrastructures, in which we are of course involved, too.

With that breadth of groups we can make sure that engagement between them is robust. It is important to me to make sure that we have authentic collaborations with our astronomy groups at the universities—with shared appointments, for example—so that we maintain connectivity within the groups in servicing and providing access to the large infrastructures.

Q214 **Carol Monaghan:** You have not mentioned industry. How does it fit into this?

Dr Dempsey: We have very strong industry ties, with over 60 different industries and companies around the Netherlands. For example, we will be doing prototyping of design and build everything from the ground up for radio astronomy. We will hand those out for fabrication and manufacture.

We are an open source development system. We are not interested in the commercial aspects of it, but there is a lot of knock-on, societal return in radio astronomy and the developments we are doing across a range of communications systems, for example.

It is a really strong network. For example, in the construction of something like the Square Kilometre Array, we are the agency that interacts with industries in the Netherlands that are getting contracts to build portions of that. So it is a two-way street.

Q215 **Carol Monaghan:** I ask the same question of Professor Kramer.

Professor Dr Kramer: Collaboration is very important. The Council of German Observatories meets twice a year to co-ordinate and foster collaboration.

An important thing in particular for universities is the collaborative research centres given out by the German Research Council, which is a combination of different universities—sometimes a cluster of universities. That brings diversity, because it includes not only universities but university research centres. The biggest result of that collaboration is to bring together different opinions and different ideas.

It is easier for non-university institutions to work with industry because of the long-term perspective that we have. We are building the first SKA dishes in South Africa with a German company. One of the main purposes of the new centre in Saxony is to foster direct links with industry in Saxony and Germany-wide. Astronomy works as a creator of innovation, and we collaborate with industry to commercialise it and make it available to the public.

It does not always work, but without industry it would not work. Schott in Mainz has produced ZERODUR glass, which is used in lithography and semiconductor production. Without that glass, which was created to build optical telescopes, it would not work. The link to industry is very important.

Q216 **Carol Monaghan:** You have both talked about the positive aspects. Is there anything that is not done well that could be improved?

Professor Dr Kramer: Politicians in Germany are trying to change the law so that we can employ postdoctoral researchers for only a maximum of four years before we have to give them a permanent position. There are not enough permanent positions in the German system, so we will not be able to hire a lot of German postdocs in the future. We will have to rely on foreign postdocs coming in and out of the country, and that is a big mistake. I do not know how much damage it will do to the German system, but I advise the UK not to limit the time contracts.

Q217 **Carol Monaghan:** That is interesting. Some of the evidence we have heard in this and other inquiries has been on the short-term nature of postdoc contracts and it is not a positive situation for those researchers. Thank you, Professor Kramer. Dr Dempsey, do you have anything to add?

Dr Dempsey: That was an astute point from Michael. We have limitations. Strict collective labour agreements in the Netherlands mean that temporary-style contracts are very short term, so we have to make them permanent rather quickly. It is a wasteful system in the academic sense, regarding PhDs to postdocs.

We could do better on both those things. On the other hand, institutes with more permanent career opportunities give options for people who might not have been going directly into the postdoctoral system and then directly into the academic system. I am actively looking at how we can have diversity of career opportunity so that we are less wasteful with our talent.

Q218 **Carol Monaghan:** I want to change direction significantly. We have had a lot of evidence that low earth-orbiting satellites are causing a lot of light pollution and bringing their own challenges. How much of an issue is this? How much progress has been made internationally to tackle it?

Professor Dr Kramer: It is a hugely important topic. It is not an overstatement that the fear is that this generation of children may be the last who can see the sky as it is today. The real threat is that 100,000 or more satellites will block our view of the night sky, affecting how we understand how small a planet in the universe we are.

This is very important for radio astronomy because satellites communicate on radio frequencies. It is a huge problem. The protected band for radio frequencies in astronomy is very small. Even worse, there are no international regulations on launching a satellite. We urgently need an international framework that limits the use of satellites in space. At the moment, every country can launch its own satellite constellation without having to account internationally.

That needs to change, so it is important that we quickly come to some international agreement regulating how space is used in that respect. It is important that Ofcom joins other voices in that regard.

Q219 **Carol Monaghan:** I was going to ask how much progress has been made internationally. Ofcom has not been part of the discussions.

Professor Dr Kramer: It has been part of the discussion, but it is always better to talk more. A radio conference organised by the United Nations is coming up in the next three years. Colleagues in my institute and in the SKA office have managed to put mega-constellations on the agenda of this big world conference. That is already a success. It is a once-in-a-lifetime chance to put regulation in place, so it will be really important that everyone in the world joins those efforts to put that regulation in place. The UK obviously plays a major role in the discussions, so it would be good to find a solution.

Q220 **Carol Monaghan:** Would you like to add anything, Dr Dempsey?

Dr Dempsey: No, I fully concur with Michael. In fact, our LOFAR telescope took some of the observations and confirmed the noise from the satellite constellations.

If we want to talk about an optimistic path, yes, the regulation needs to be there and, yes, there needs to be serious investment and collaboration from all the industries that are making noise and light, if we want to see the sky.

I have seen examples of those kinds of collaborations in the Netherlands. We put an SKA in South Africa and Australia for a reason: they are as far as we could possibly get from civilisation. Every part of our civilisation now makes radio noise, yet we have a telescope—one of the most sensitive in the world at these frequencies—operating from the heart of Europe.

That should not be the case, but 10 years ago it was predicted that LOFAR would not be able to hear or see the sky at all. Part of the success has come from the engagement with the 5G networks, with the wind farms, which make noise, and with the solar farms, and agreeing to make adaptations and changes to their systems to comply with the level of radio silence in the frequency bands that we need.

These are examples where, with engagement and investment with local industry or industries doing this, and if you have enough support at governmental levels to do so, there are ways to mitigate things that otherwise would be prohibitive. So this is possible. We are already innovating in a host of different ways to filter out noise, and they all have direct commercial and societal applications. A lot of them have had unexpected knock-on benefits.

We need not just regulation but buy-in from the industries that are causing this in order for these things to be successful, but there are examples where that does happen.

Q221 **Katherine Fletcher:** I appreciate your time very much; it has been a really interesting inquiry.

One of our roles is almost to join the dots back up. We have been particularly interested in AI. What are your thoughts and views on what role AI is playing in astronomy? Dr Kramer, you spoke of projects needing to be able to react to innovation. I think that AI comes into that bucket, does it not?

Professor Dr Kramer: Absolutely; it is a completely correct question.

When I was still in Manchester we were one of the first to start to use machine learning to look at the flood of data from our telescopes to identify the objects in the noise that comes from every direction. It has since become even more important. Nowadays, when we do an experiment in South Africa we use a telescope that was a precursor to SKA. We collect 3 petabytes of data every night. In the past, we had postdoc students going through the data to sort out the interesting signals from the noise. That is not possible any more. We cannot save the data, so it has to be online, with machine learning, new networks and artificial intelligence. Without that, it would not work any more.

There are countless examples in astronomy where the flood of data that we are now facing—it is a good thing, not a bad thing—comes with challenges for which we have to deploy machine learning and artificial intelligence. The only problem and risk, which is clear, is that astronomy is a discovery science. The biggest insights into physics and astrophysics were completely unexpected because of some serendipitous discovery. Now we have to make sure that the artificial intelligence that we pass the data to does not skip over or miss the unexpected. We need to train the artificial intelligence. We need to make sure that it identifies the interesting signal.

That is a big challenge, but again there are some interesting industrial applications. We can develop many methods in astronomy and astrophysics that can find applications in society. Smart cities will have the same amount of data as radio telescopes have today. You might want to find a glitch in a power grid. You might want to find a particular problem somewhere in the data. With the methods that we have developed in astrophysics and astronomy, you will have the same tools in your hands and can apply them to other interesting projects.

With autonomous car driving, the amount of data you receive and you have to process would not be possible without artificial intelligence. Astronomy, particularly radio astronomy, already has the dataset to do the training and to learn the methods. We can play an important role.

Q222 **Katherine Fletcher:** What do your Government think about it? Governments around the world get together and there are two areas of concern, at least, in terms of the safety and the size of the cheques that need to be written to process that amount of data, if I can put it in Mancunian to make you feel slightly at home. How does your institute get on with Government? Do you feel supported?

Professor Dr Kramer: Yes and no. More can always be done, but having received a cheque for €1.3 billion to build a centre, one of the pillars of which is based on data science and artificial, is not a bad thing.

Compared with the money spent elsewhere—not on astrophysics—there could be more. The nice thing about astronomy is that our data does not have any approved forms for data security and data privacy. That is why a company like SAP—one of the biggest software companies in the world—came to us to ask, "Can we use your big datasets to try our methods and algorithms?" They did not have to worry about data privacy issues.

I think there can be a link; if industry understands that we have the datasets that it can work with, and government funds it, that will be ideal. I will not complain that there is not enough funding; but there can always be more.

Q223 **Katherine Fletcher:** That is fair enough. Dr Dempsey, what would you contribute on that? Are there any reservations from your perspective?

Dr Dempsey: Yes, I am going to give quite a different perspective from Michael's. I am very cynical about AI—the numbers and the questions that are being asked right now are going to suck the air out of the room, funding-wise; I do not think it does. Radio astronomy is, as Michael put it very well, only the first of many research challenges that are going to hit data bottlenecks.

Before, in astronomy, the precious commodity was hours of time on the sky with a telescope. With SKA and LOFAR, that is not the case; it is whether you can afford to reduce the data. Can you afford the processing and the data footprint, to keep it somewhere? That is already a big paradigm shift, with the amount of money required. AI will not solve it on the timescale we need. We need to look carefully at where the funds are going. I do not necessarily think that all of it going into AI, because of the opportunity matrix, is going to give us back potentially everything we need.

The other part of this is the energy and carbon footprint with the scale of the data need. Until now in astronomy, every time we have made an efficiency gain in our algorithms we have used it to do more science and consequently increase our footprint. Those numbers are ever-expanding, so if we are going to look at sustainable or green astronomy, and at trying to be accountable for our footprint and energy budgets as well as costs—because of course they are completely aligned—we have to be far more strategic about where we put our gains and what we decide to do on the limits. The major cost in the future will be in the energy budgets of our data processing and archives. I am very cynical about whether, on the timescales we need, we should be putting all our funds in AI to figure that out.

Q224 **Katherine Fletcher:** That is an interesting point. What would you suggest as an alternative to investing in AI, at this scale, if discovery is still the primary goal?

Dr Dempsey: Green computing. We need to look at really investing in technology developments on every part of the data collection chain, and how we turn them green.

Q225 **Katherine Fletcher:** Oh, right, I understand; so it is kind of a mechanical improvement in the data process rather than an alternative to collecting mass datasets.

Dr Dempsey: Yes, we actually do need it—not just mechanical but algorithmic. Some of these can be things where AI is going to help us; but it will not be the only solution. We need a broader strategic view on minimising these footprints—maximising our output and making sure it has the minimum footprint. AI has that huge energy demand, which is a reason to look at putting the factories where you can generate the energy to do so. My worry is that that is an ever-expanding void into which we will pour money. I want to make sure that we get the outcomes from it that we need.

Katherine Fletcher: So, as to scale, I am being slightly daft but you need a nuclear reactor in the Sahara, or an extra telescope in the data centre, or a huge solar farm; you need to start providing the energy for the storage and production of the datasets in a sustainable way. Understood. Thank you so much.

Q226 **Dr Davies:** I am interested in amateur astronomers' access to facilities in your countries—observatories, planetaria and radio astronomy facilities.

Professor Dr Kramer: I think that that is something Germany can be very proud of. We have about 40 or 50 planetaria across Germany that can host more than 50 people. We have 10 that can host more than 300 people. They get hundreds of thousands of visitors. We also have small popular observatories, mostly run by amateur astronomers, where you can get to a telescope and observe. They are usually small telescopes, but not all of them. Some are sizeable.

Germany is sometimes not the best country for optical observation of the sky—just like Manchester—but people are really drawn to this. Last year, we had something funded by the Ministry—to build a moveable planetarium. We went to the pedestrian zones in cities in Germany. We also wanted to direct people to the planetarium who would not usually go there. That was a huge success; we got 60,000 people on that tour across Germany.

We also do teacher training. We make sure that there is organised teacher training across the country and we invite teachers from high school. We have brought research results to the schoolchildren, and so on.

We have not done very well in bringing the public to participate in real optical and radio astronomical research. With radio astronomy, there are only so many things you can do with a telescope; and it does not have quite the appeal to the public, because you only see some data stream coming out. You cannot see something with your own eyes. There is nothing better than looking through a telescope and seeing the stars, Jupiter or Saturn with your own eyes. In principle, this is very well developed in Germany. Just this morning I got an invitation to participate in teacher training again.

We also have the House of Astronomy in Heidelberg, which organises teacher training in Germany. It hosts the International Astronomical Union office of astronomy for education. This is taken very seriously in Germany and we can really be proud of it.

Q227 **Dr Davies:** You have touched on public outreach in Germany. Do you have any comment on methods that work in engaging the public and schoolchildren? You have talked about some of what is in place, but how can those efforts best work?

Professor Dr Kramer: I think you would be amazed. If you give a talk at school—even in primary schools—the questions from the students are really amazing. They want to know about black holes and stars, and they are very intelligent questions—sometimes so intelligent that you have to think about the answer for a while. Exposing these kids to astronomy at this very young age is a draw into STEM fields later. We see this all the time. I think they can be engaged with nice pictures, and the planetarium, and trying to show them and teach them about the fascination of the universe. Aliens are always a favourite topic, of course. Someone said that the most attractive things are dinosaurs and space, and I think that is true.

By getting these schoolchildren very early, I think we can draw them into STEM research. They may not become astronomers, but they will certainly be interested in natural sciences and engineering, and so on. I think there is almost nothing that would not work if you tried to excite them, because they are really fascinated by the subject.

Q228 **Dr Davies:** Very good. Dr Dempsey, in the Netherlands what is the state of play with access to facilities for amateur astronomers, and how developed are the relationships between professional and amateur astronomers?

Dr Dempsey: It is very comprehensive. I would second Michael on one thing, which is that there are not many places worse for optical astronomy than the Netherlands, so we are quite limited as to the size of the optical facilities.

With the radio facilities, there is an example directly outside my office window. The Dwingeloo telescope was built in the 1950s and has not really been scientifically competitive since the 1990s. However, it was taken over by a group of retired ASTRON employees, and they found funding and renovated it. It is now a public access facility that they allow any amateur and student astronomers to use. The renovation made it look better, I think, than originally. It operates nearly every day. They are incredibly invested. In the summer, which we are just going into, 1,000 visitors come and do this. They track cube satellites and they tracked the Artemis mission when it went to the moon. It is an incredibly active group.

That is what you see with amateur groups. When they are engaged, and are supported by the professional astronomy of a region or nation, they are just self-propelling. If you can give them the support, which does not necessarily need to be monetarily very large, they enable an entire other engagement set from what most professional astronomers either have time for or might have interest in.

Q229 **Dr Davies:** How do you feel public outreach is working in the Netherlands in general, and, again, what methods do you think work best?

Dr Dempsey: I think it is an incredibly diverse and high level of engagement. I am very impressed, here in the Netherlands, with the diversity of types of engagement. For example, in Nijmegen there has just been this very heavy indigenous art exhibit focusing on black holes. It is a combination of artists, with written work and the event horizon telescope: discovery—space. They are very creative. As Michael mentioned, this makes it accessible to people who otherwise might not have turned up for an astronomy talk. Such collaborations with writers and artists—I have seen a lot of very successful ones—really broaden the engagement set from the typical one that you might see in general outreach talks. I think those are vital but they should not be the whole suite of ways in which we engage.

Something else interesting—I learned this in Hawaii—is that community engagement does not necessarily mean scientists talking to the community about astronomy. It may be just being a better community member, so that you get to be part of that community.

We opened up the telescopes on Mauna Kea for high school students to ask for observing time. This was an incredibly successful programme. Michael already mentioned that kids end up surpassing your expectations. We thought they would come up with some very basic requests. Some of the programmes that were awarded some time were so ambitious that we could not do them with the best telescopes in the world. Some of these high school students even published scientific research papers with their graduate students in the universities. It was a really impressive way to engage. Some of the students, as Michael also mentioned, ended up not going directly into astronomy but staying in STEM, which they might not otherwise have done, because they had such an authentic early experience.

Dr Davies: Thank you very much for that comprehensive reply.

Q230 **Graham Stringer:** What has happened to funding over the last 10 years in the Netherlands and Germany? Dr Dempsey, has it increased or decreased, or stayed level in real terms?

Dr Dempsey: I have only really come into the landscape recently, but, of course, I have been catching up on my history quite quickly. I think it has been quite steady, and we have had significant wins such as the Square Kilometre Array investment. The Netherlands is a member. For the Netherlands, which has a limited budget compared with Germany and the UK, that was a significant additional investment to the portfolio. I would say that it has been quite steady, with really consistent success across the optical, infrared and radio astronomy regimes.

Professor Dr Kramer: In Germany, research funding in general—not just related to astronomy—has increased significantly in the last 15 years or so. Governments, across different constellations, have increased the research budget, under the so-called pact for innovation and research, by between 3% to 4% every year for the last 15 years. That was very important. Looking at astrophysics, and astronomy in general, funding had to be level, which, in real terms, because of inflation, means there has been less money in the system generally. As I said, the funding of the national centre is of course a welcome boost. I think we are complaining from a very high level. Funding for research in general has increased, but for astrophysics it has probably been level, with a real-terms effect of reduction.

Q231 **Graham Stringer:** Dr Kramer, one of your professorial predecessors at the University of Manchester was Lord Rutherford, who said, "We have no money; therefore, we have to think." Is there a future for astronomy that does not use very expensive kit and AI? Is there a low-cost future for astronomy?

Professor Dr Kramer: There are some niches, I think, where the unexpected discovery or new insight will always be possible, but it is unfortunately true that the machines that we need to make discoveries are getting bigger and bigger. Unlike machines in some other sciences, maybe, our telescopes and observatories are multipurpose instruments. That means that you may have a great idea, and when you go to the telescope you find something unexpected, which the telescope was not built for. If you go to any telescope, the biggest discovery made there will not be the one that was envisioned when it was built. It is important to keep that in mind.

Yes, new telescopes get bigger and more expensive, but they also shift the parameter space that you are exploring. You discover really great new insights into the physical world—not just in astrophysics, but in fundamental physics in general. Think about dark energy and dark matter, which we still do not understand.

Much as I would like to say yes, there is research that can be done on a shoestring, I think that the fact is that international competition is so high that you would be outperformed by the new facilities, and if you are not part of that you will miss some of the most exciting results. Unfortunately, I am a little pessimistic about that being possible.

Q232 **Graham Stringer:** Thank you. Dr Dempsey—the same question.

Dr Dempsey: The short answer is not if we want to be competitive. I am, however, a proponent of the fact that just asking for something but a bit bigger, without any thought as to why, has gone the way of the dinosaurs. We now have to be far more strategic in the way we step forward into larger facilities. I particularly believe that they have to do 100 things for 100 different science cases. Right now, if you are going to invest, you have to demonstrate that it is not an experiment from which one person will get an accolade. Gone are the days of that individual scientist writing a paper, and a Nobel prize justifying the scale of the funding that we are talking about. The discovery engines of the future will not be driven just by scientific greed—bigger, better, faster, stronger—but will need to open up a new dimensionality. They also need to demonstrate that they will meet the needs of a range of scientists in the community.

Finally, the days of single country investments are gone. When you see how many countries have said that, yes, the SKA is a priority for them—you have to have robust international collaborations, and you have to share. Those are the things that will meet the success needs for competitive astronomy in the future. They are not cheap, but we have to make sure we are not wasteful. That is where I think we have to move from that competitive nature—"Let's just all build one and may the best person win"—towards saying, "Facilities of this scale are too large and the funding needs are too great for us to do that." A little bit of a paradigm shift is needed. If we are going to invest in these beautiful big toys, we have to make sure that the toy lasts us two generations at least.

Q233 **Graham Stringer:** You both mentioned the career insecurity for postdoctorals, because of the difficulty in getting permanent positions and the short-term nature of initial contracts. You have also said that it is easier to inspire children with dinosaurs and space—and that is true. Given the insecurity, what vision of astronomy do you give, in the future, to someone in their second or third year of a PhD course, to say, "Astronomy is a great career for you; there is a level of insecurity but there is real excitement out there"? How do you inspire those doctoral students?

Professor Dr Kramer: I think the motivation is there almost by itself. They are very inspired. What you have to tell them is that the number of positions is limited. We produce many more PhD students and degrees than there are positions in the system; but their skillsets and training are very useful for different careers, and many move into those different careers. The main point is to be very honest about that.

What I miss in the German system, which is great in the UK system, and which I have enjoyed myself, is a career path that we do not have in Germany. At university, you can start as a lecturer and move through senior lecturer, reader and professor, and so on. That career path does not exist in Germany. When I talk to my students, I tell them you may have to be prepared to move around until you find a position. That is exciting, because you meet new people and cultures, with all the benefits that come with that.

That is also part of the motivation, because you work with these incredible, bright people from across the world, from different backgrounds and cultures. That is one of the motivations for doing astrophysics, because it is collaborative research. You need to be flexible. We would like many more permanent positions and a certain career path in Germany, but unfortunately it does not exist in this country, which is really a shame. The UK is really much better off in that respect.

Q234 **Graham Stringer:** Thank you. Dr Dempsey.

Dr Dempsey: I think that in the Netherlands a couple of interesting conversations are happening. I am very sensitive to this. I was not an astrophysicist by training. I drifted into instrumentation because I liked building things with my hands. I enjoyed that. That was very damaging on an academic career scale, because when you are building instruments you do not publish enough to be competitive with people who are sitting crunching data and producing 10 papers a year. I am very sensitive to the need to provide different kinds of recognition for different breadths—not for just the pure academic research in astronomy. We need instrument builders, too. We need the ones who are interested in the software and algorithms and want to do all those things.

There is a reward and recognition analysis going on right now within the whole Dutch research infrastructure—not just astronomy—with the recognition that we need to change the way we reward, and not just to reward publication, citations and the traditional scientific metrics. We know that this also unfairly helps certain demographics over others. Women and other under-represented groups are more damaged by just having these different levels of reward.

The conversations that are going on are really interesting. We are seeing some changes at some of the universities. These are things I am now enacting at ASTRON to try to broaden the workforce funnel. We are doing incredible training, and we are losing incredibly valuable people from the system when I need to keep them in something else. I want the system to be a lot less wasteful in trying to find and broaden viable career paths and to give opportunities, perhaps, to return to academia after helping to build our telescopes. That is ongoing at the moment. There are good lessons to be learned, I think.

Q235 **Graham Stringer:** My final question is on big, long-term priorities. You have said it is getting more difficult to see into space and make observations from the earth. For long-term investment, does that mean that in international collaboration we should be prioritising space-based telescopes rather than terrestrial telescopes?

Dr Dempsey: I think you might have seen some conversations recently, about begging the world to keep the dark side of the moon radio-quiet. It is the best platform we will have in the next century for looking at space. Yet, of course, with a second space race going on, there is already the potential for us to lose that opportunity. There are credible missions on the moon already—and about to go—that will start to test this field. I think we will be looking at the next generation—optical and particularly radio astronomy: we need to get above our ionosphere, not just above all the noise we make as humans, if we want to really see and open up that space beyond what we have now.

It is definitely going to be the landscape of the future—CubeSat arrays or compact arrays and, potentially, missions to the moon. That is an important strategic viewpoint. I know a lot of conversations in the astronomy world, and collaborations, are happening around this. I think that will be the next generation of telescopes.

Professor Dr Kramer: I have a slightly different view. We are building instruments like the Extremely Large Telescope of the European Southern Observatory, which will be almost 40 metres across. It will be the biggest and most powerful telescope in the world for the next 10 years. The Americans will have nothing to compare with it. That structure cannot be built in space. You can still do amazing science from the right places on earth. You have to worry about conservation, but the amount of money it would cost to build such a structure in space would mean we would have to ask whether it was worth spending it. I think there needs to be a mixture.

There is certainly room for certain space observatories, as we have them today. The JWST has produced wonderful, amazing and unexpected results, but it was also the single most expensive astronomical instrument in the world by far. I do not know how many of those instruments we can build simultaneously. China apparently can do it quite well—not JWST-style. My point is that from a training and industry point of view as well, having instruments on the ground means we can bring our industry there. We can build a diverse set-up of industry and different skills, and train our people there—engineers and astronomers. I do not think that anything will replace the importance of the ground-based facilities, but there is clearly some scope for space-based instruments, as Dr Dempsey has pointed out. I think we still need ground-based facilities.

Q236 **Stephen Metcalfe:** I would like to talk a little about diversity. Dr Dempsey, you touched on this. We are told that one in five of the workforce in astronomy is female, globally. It may be a bit better internationally and a bit poorer here in the UK. Does it matter that it is only one in five? If it does, why? What can we do to improve that and what is your experience, as someone who has worked in different places around the world?

Dr Dempsey: Personally, I am going to tell you it matters—only because I have seen the waste and damage. The reason it is one in five is not because not many women out there want to do it. It is because the losses across the entire level of the career field are greater for women. There is something broken in the system, and bias in the system, when we lose women at a greater rate at every career stage. By professorial or directorate level, where I am, it is down more to 2%. At senior levels, we lose a large amount on very small numbers. If the role models are not there, it is far harder to continue to recruit into the system in the first place.

So role models are the start, and the second part is training in policy making to make sure that you do not lose women at each stage. It is perfectly possible. An example is the systems that I put in place at JCMT in Hawaii. We went to gender equity across the entire organisation within 18 months, even in our technical fields. At ASTRON we have just put in something called an equitable hiring campaign. This is where you look to your recruitment processes first and foremost, and your retention, secondly. Those two things have to go hand in hand; but those are systems that work, and you can do it.

I think there is a different experience for women in astronomy because of the small representation; and I would extend that to other under-represented groups—not just women. You can tell the difference in quality, experience and performance when groups have worked to make sure they have representation and a more diverse group—and that it is inclusive in how they are appreciated.

Q237 **Stephen Metcalfe:** Thank you, that is very helpful. Professor Kramer, do you want to add anything to that from your own experiences?

Professor Dr Kramer: No, I think what Dr Dempsey says is absolutely correct. This has been neglected for far too long in Germany, but there have been major advances. It is not perfect. We can do much more. We should do much more. The Max Planck Society has a self-commitment that a minimum of 30% or 35% of directors at the Max Planck Institute should be women. We have excellence programmes for women candidates where we make sure they have career options and fall-back options if they do not make the tenure track. We try to give them security.

It is not enough. We have to do more. This programme has installed role models whom Dr Dempsey was talking about, and from then on we need to make sure that the lower levels are populated accordingly so that we have bigger pools of diverse people we can draw on. That sometimes takes time, unfortunately. I am amazed by the 18 months. I can only congratulate you, Jessica, on having done that. We find it much more difficult. It is a slow process, but it needs to be done. It does matter.

Q238 **Rebecca Long Bailey:** To build on what Stephen Metcalfe has just been asking, what, Dr Dempsey, is the position in relation to diversity regarding people from a black and ethnic minority background as well as a lower-income background?

Dr Dempsey: Absolutely. I can give you stats off the top of my head for about 10 countries. In the Netherlands, it is very problematic. It is not representative, particularly of the Dutch ethnic minorities as they are acknowledged. They are just non-existent in the astronomy landscape. It is a completely non-existent profile. Beyond high school, even if they are going into universities, they are not going into the scientific areas. It combines both the fact that there is a bias in what they are experiencing in high schools and the fact that they are generally in those lower-income areas and in those lower-income schools. There is a compounding factor that causes that imbalance and that lack of representation.

This has been shown time and again in US studies. In Hawaii, we see native Hawaiian groups being mostly in the lower income to absolutely under the poverty line experience. These two things compound to mean that, regardless of the fact that Hawaii has had astronomy for 60 years, less than 2% of the astronomers have any native Hawaiian background. There are efforts to change that by overcoming that combination of the lower income and lower education opportunity level. We see fewer of them in astronomy. We also see a far lower representative number of people of colour and minority ethnic background in astronomy worldwide.

Q239 **Rebecca Long Bailey:** Thank you. Professor Kramer, what is the position in Germany?

Professor Dr Kramer: I am afraid it is very similar. We have a huge gap in ethnic diversity. We have a number of Asian-background colleagues in upper places, and that is good, but the diversity aspect, in astronomy in particular, is not very well taken care of. More needs to be done. In terms of lower income, fortunately, education in Germany is completely free. I was the first in my family to go to university. It would not have been possible without it. There are chances. Lower income is maybe less of a problem when trying to help ethnic diversity.

Chair: I thank Dr Dempsey and Professor Kramer very much for their evidence today. It is very clear, very direct and very helpful to our inquiry, so thank you for joining us.

Examination of witnesses

Witnesses: Professor Nicolas Thomas and Mr Gabriele Cremonese.

Q240 **Chair:** I am now going to introduce our next pair of witnesses, who are also appearing virtually. Professor Nicolas Thomas is professor of experimental physics at the Physics Institute of the University of Bern. He has held a postdoc research fellowship at ESA, the European Space Agency's space science department, and has been a principal investigator in the past on missions to Mars and has worked on missions to other planets, including Mercury and Venus.

Mr Gabriele Cremonese is a senior technologist at the Astronomical Observatory at the University of Padova in Italy and of the National Institute for Astrophysics. He has been principal investigator to several missions as well, including Mercury and Mars, and belongs to ESA's PROSPECT science team. Thank you very much, both of you, for joining us this morning.

Professor Thomas, thinking, in your experience, about international relationships and relationships within countries, what is required to make sure that science and instrumentation come together to contribute to international missions, in which you are very experienced?

Professor Thomas: First, thank you very much indeed for inviting me. I am quite honoured to be asked.

There are relationships that are necessary on many scales. At the national level, it is important to have good relationships with your space agency because it has to be aware that you are interested in proposing to a particular mission or proposing a particular experiment. You have to have a good relationship and good knowledge of the capabilities of local industries.

In Switzerland, if an instrumentation project receives money, 50% of the money must go to industry. There is a little bit of flexibility, but it is a requirement.

International collaborations need to be fostered because most instruments cannot be funded by one country alone. That is even true on planetary missions that typically have smaller instruments than the big astronomy missions, but it is still true that you have to have relationships with international colleagues and know what they are capable of doing.

If I would like a power converter for my next experiment, I talk to my colleague in Spain or my colleague in Poland and see whether they are able to do this. Knowing that that landscape is there is an important part of trying to get yourself into a position where you can propose an instrument for a mission.

Q241 **Chair:** That is very interesting. To be successful in your endeavours, a lot of the skills that are needed are outside the lab and universities—diplomacy and attracting business investment, I guess. How do scientists starting out, presumably through PhDs and others, quite narrowly on papers and in labs, develop these important skills and attributes?

Professor Thomas: That is a great question. As you are aware, we were briefed before the presentations here, and this question came up. I spent some time thinking about whether there is a road map towards this, and it is difficult to say that.

One of the things that I concluded is that the postdoctoral people who are most likely to go in this direction are those who have been playing around with data on a previous mission in some way or another, and they are asking themselves questions, or saying to themselves, "It would be nice if I knew this. It would be a lot better if I knew this. I could really do something if I knew this," and then they take it a little step further and say, "Yes, but what type of instrument would I need to build to get that information?" The minute that they ask themselves that question, they are already beginning to move away from being a pure data analyst towards thinking to themselves, "Well, could I get an instrument built?" That is one of the first steps.

Clearly, that is already telling you that somebody has to be in the field at PhD level and postdoc level to be starting to ask themselves these questions. Then they have to collect the experience that says, "I do not know about how to build space instrumentation. Where do I get it?" You go to a place that allows you to start seeing what can be done. That means going to places like ESTEC, as I did. Several other people whom I know also did fellowships with the European Space Agency. I also went to the Max Planck Institute. As Professor Kramer is on there, I was at the Max Planck Institute for Aeronomy, as it was. It is now the Max Planck Institute for Solar System Research in Göttingen. This institute was quite famous for building space hardware. Then you collect that experience. Making sure that people can move around to collect this experience is also an important element of this.

Q242 **Chair:** That is very interesting and perhaps leads to my follow-up question. You have described, in some ways, entrepreneurial skills among scientists prospecting for contacts and influence. Can public policy help to support or provide some scaffolding to assist that?

Professor Thomas: Yes, there are certain things. The first thing is obvious: to provide funding to allow people to go to the places that they want to go to for research, rather like the Swiss National Science Foundation, which has a postdoc mobility grant. I think that the same thing exists in the UK, but I have not lived in the UK for nearly 40 years, so I am not so familiar. The Swiss National Science Foundation has this postdoc mobility that allows people to come and say, "I want to spend 18 months at Caltech," and they can go out there and gain experience. That is one thing that you can do.

The Americans have programmes that teach people to become principal investigators for instruments. We do not do that in Europe. We certainly do not do it in Switzerland. When I did my first PI job, it was totally learning by doing, and mistakes were made, but that is how it was. I survived. None the less, it would be better if there was some sort of educational programme.

The European Space Agency ought to be the right address for this, but the European Space Agency often takes the position that it is responsible for building spacecraft and the instruments are the national agencies' responsibility. It says, "Well, it's your job. You should go away and do that." I do not agree with that. The European Space Agency should pick up that role and try to educate future PIs.

Q243 **Chair:** That is very interesting. Professor Sir Jim McDonald in Glasgow talked about a triple helix of funding bringing together the public sector, universities and industry. That seems to be what you are describing as being necessary for success in this field.

Professor Thomas: Yes. In Switzerland, they have imposed the requirement to have a significant part of the financing going to industry. That has its good sides, but it can sometimes go wrong if you try to put out something to industry that is not terribly well developed or requires a significant amount of R&D order to make it work. A lot of the time, we are doing very new things, we are putting things in very new environments and so on. It is not a given that industry has the expertise to be able to do that. The universities know exactly what they want, so they are often in a better position to do that.

We are building the main imaging system for Comet Interceptor, which is an ESA small mission called an F-class mission. We are getting the parts of the telescope—the carbon fibre structure and the mirrors and so on—all integrated from industry because it is very good at that and it knows how to do that. There are some changes that need to be made, so it gets some engineering work as well. That all fits together very well and it can deliver that, and that should work nicely. If you want to get it to do new developments, this tends to be a little more challenging.

Chair: Thank you very much indeed. That is a fascinating insight. James Davies has some questions to Mr Cremonese.

Q244 **Dr Davies:** Mr Cremonese, in Italy how joined up is the space and astronomy sector in research, technology and Government support?

Mr Cremonese: In Italy, most of the space sector—

Chair: I think we have lost your sound, Mr Cremonese. I do not know whether it is our end or yours.

Clerk: I can hear you Gabriele but you need to speak closer to the microphone.

Mr Cremonese: Okay, I can try now.

Chair: No, we do not have it.

Dr Davies: It is very quiet. That is the problem.

Mr Cremonese: I will try to speak louder. Is that okay?

Chair: No, it is not, I am afraid. Is there anything at your end that you can tinker with?

Mr Cremonese: Okay, I can try now. I will change something with the set-up. Is it okay?

Chair: No. I am afraid we cannot hear you.

Q245 **Dr Davies:** That is a problem. Perhaps I can switch to Professor Thomas while we figure out whether there is a solution.

Where there are national launch capabilities, what advantages do they give to astronomers?

Mr Cremonese: I got the question.

Q246 **Chair:** I am afraid, Mr Cremonese, we cannot hear. We can see your lips moving, but that is it. Professor Thomas can take that question, and then we might try the telephone or something like that.

Professor Thomas: Yes, national launch capabilities. Switzerland, of course, is a relatively small country. It is one eighth of the size of the UK population-wise, and our spending on space is probably about a third or a quarter of what the UK spends. There is no national launch programme. There was a start-up company called S3 that started up around about 2014, I believe, but it went bankrupt relatively quickly in 2018.

We do not think that, at the moment, it is viable at a national level for Switzerland. In general as well, if you want to get into that market, it is very competitive now. In order to get into that market, it requires quite significant investment and a large number of customers for that activity. You have to guarantee that, so checking the market is very important.

Q247 **Dr Davies:** It is difficult to deliver, particularly in smaller countries, but it gives big advantages to astronomers, I presume you would agree, where it is possible.

Professor Thomas: Yes, of course. We have also tried rather hard to look at ways in which Switzerland can expand its palette of things towards the higher end such as building spacecraft and so on. We have looked at that and done some activities in that area. If you are able to launch your own spacecraft, yes, this has advantages, particularly for looking at some of the niche areas that Professor Kramer talked about a little earlier. We found one of these niches with a programme called Cheops, which was a joint programme between Switzerland and the European Space Agency. It was a low-cost mission; it was €50 million from Switzerland and approximately €50 million from the European Space Agency. It was following up transits of planets across the faces of stars and monitoring that. It has done a great deal of work relatively cheaply in a niche area. We are not launching it; we are simply having bilateral agreements with people who can launch for us.

Chair: Let us try bringing in Mr Cremonese now that he has his headphones on. We will see whether that is making a difference. Can you say something to us?

Mr Cremonese: Yes.

Dr Davies: That is better.

Mr Cremonese: Can you hear me better now?

Chair: We can, yes, absolutely. James, do you want to ask your question to Mr Cremonese?

Q248 **Dr Davies:** Can we go back to the original question? How well joined up is the Italian space and astronomy sector in research, technology and Government support?

Mr Cremonese: In Italy, most space activities are directly funded by the national space agency, ASI. There is research and development in the research institutes and the universities. To be involved in large projects with big instruments aboard a space mission, we have to work with ASI, the national space agency, to get funding.

It is important at such a point to have strong collaboration between the universities and research institutes. I am an employee of a research institute where I do not have a duty to teach, unlike my colleagues in universities. It is important to collaborate with universities because for my long-term project I need PhD students, and it is only by collaboration with universities that it is possible to get students and people to pay for postdocs later.

The space agency can fund the realisation and the operations related to the space instruments, but the research and data analysis are done by the research institute rather than the university, even if sometimes the funding that we get for the large projects for space instruments is enough to do research, to prepare the observations and to analyse the data that will be acquired by the instruments.

Q249 **Dr Davies:** From your understanding, what could the UK learn from the Italian approach?

Mr Cremonese: One important point is that the people can stay with us without having a permanent position. In Italy, we can pay for six years for a postdoc, and then there is another fixed-term contract after the PhD for research without any limits. It means that I can pay for 10 years for people working on my project.

This is important, because I am involved in the BepiColombo mission that started 24 years ago and arrived on Mercury in just a couple of years. If I had to change the postdoc every three years, it would be a nightmare, because every three years I would have to hire new people and teach them in order that they have the right experience and competence that I need for the project. The most important point is the possibility to pay postdocs for longer times in order to arrive at the target of the mission with the people who started with me at the beginning or in the middle of the project.

Q250 **Dr Davies:** Finally, can I go back to the second question about national launch capabilities and how useful they can be to astronomers? What is your perspective on that?

Mr Cremonese: In Italy, we have a small launch capability, or we have to ask other entities such as the European Space Agency. That could be important because there are large projects and large missions. If I need to validate some technology or a new kind of instrument, maybe I will start with a small prototype. The small prototype means that it needs the launch of a small satellite such as a cube satellite. CubeSats are a well-acknowledged technology. Several people and several groups tried to get funding to get instruments on board CubeSats that could be launched by small launch capabilities available in Italy.

I am a planetary scientist. I am on a space mission to explore planets. ESA will be able to test a small prototype of an instrument by flying it in a CubeSat around the Earth and will be able to validate my instrument very well and it could be ready for other deep-space missions.

Q251 **Rebecca Long Bailey:** Professor Thomas, one of the common themes across many countries that we have spoken to so far is the long-term certainty of funding. Do you face any challenges in the research that you are involved in to ensure that funding extends for the entirety of a mission or programme—from the early stages all the way through to data analysis?

Professor Thomas: Yes, indeed, we have problems. It is one that is quite common in Europe because there is a separation of instrument development operations and data exploitation. In Switzerland, there is adequate and well co-ordinated funding for instrument development. There is now something that is in place for the operations of the instrument, but the data exploitation, and the science from that exploitation, is funded by a different entity.

There is a difference between the Swiss Space Office, which is under the Ministry and is responsible for instrument development, and the Swiss National Science Foundation. There is a disconnect, and it has resulted in some difficulties and tension in the system.

It is particularly difficult because the Swiss National Science Foundation, quite rightly, is attempting to have competition and tension between grant applications and proposals in order to try to make a choice and choose the best, but if you are an instrument developer—it was explained a little earlier by Jessica—you can be spending eight to 10 years developing that instrument, and at that time you are not devoted to science and writing research papers in anything like the level that your potential competitors are, so that creates a problem in the competition area.

In addition, there is a bit of a moral problem, because getting these instruments on to spacecraft is not easy, and you get challenges and difficulties and sleepless nights worrying about whether you are going to be able to make it or not, and at the end it is said, "Well, okay, you've done that. We do not care about the reason you did it to get the data. That's it." That is not really a great way to do business.

Q252 **Rebecca Long Bailey:** Mr Cremonese, we spoke in our previous session about the collaboration between business and research, and one area that often does not get the focus that it deserves is the application of astronomy technology to non-astronomical applications. What support is available in Italy to translate astronomy technology into non-astronomical applications?

Mr Cremonese: This is not always followed in technology transfer. In our research institute, there is a small technology transfer office to adapt something that we realise for ground-based telescopes or for space missions to the daily lives of the public. This sometimes happens, but not always. Sometimes, we need more funding because if we adapt an instrument to the daily lives of the public we need funding to modify something and to teach people to use it.

Something is possible if there is collaboration with a private company. The private company could be interested in the scientific purposes, but later we need to have a gain in something. It means that they need to transfer the instrument technology that we realised to the public to other applications, and sometimes it happens.

During the pandemic a couple of years ago, a few people from our research institute who are expert in astronomical instruments for the exploration of Mars and the moon used the sensors and detectors to detect the virus in buildings in the city. That was patented in order to apply that specific instrument to the daily lives. That was useful during the pandemic.

Q253 **Stephen Metcalfe:** I want to change track slightly, if I may, and talk about the role of amateur astronomers in the overall ecosystem. Could you both describe what role they play and whether they receive active support from their professional counterparts? Who would like to start? Nicolas.

Professor Thomas: Yes, sure. "Nick" works for me as well.

We have lots of contact with amateur astronomers, and indeed some of our staff are members of amateur astronomy societies and help them with observing strategies and guidance about how to get astronomical observations.

We also run an observatory on the Gornergrat, which is there also for amateur astronomers. It is a remote telescope, but none the less it is capable of doing things. A number of telescopes are run by amateurs around Switzerland. One in Schwanden doubles as a planetarium and is open to the public, where they give presentations and so on. That was basically done by one person, as a matter of fact, who really energised that.

The best that we can do with data coming down from space and from the cameras that we have currently running around Mars is provide it openly to amateurs who want to work with it. We try to do that. There is a certain amount of time that we need to process the data before we can put it online, but we are managing to do that with a delay of about a few months after it has been verified, and so on. Amateurs can then touch that.

You will be aware of some of the work that Chris Lintott has been doing with citizen science. One of the programmes is called Planet Four, which is looking at geysers on the surface of Mars. One of my previous postdocs, Anya Portyankina, and her husband, Michael Aye, are very heavily involved in that. We try to support that as well by making data available and so on.

Q254 **Stephen Metcalfe:** What about the other way round? Do amateur astronomers help you in any way; do they collect data; are they able to do observations on a grander scale, or is it one-way traffic?

Professor Thomas: It is not so easy any more. Paul Wild discovered his comets from the Zimmerwald Observatory in Bern. It is very difficult to do that any more because the professionals are doing it now with all-sky surveys and the like. For planetary activities at least, all those low-hanging fruit have now been taken over to a large extent by these large-scale observatories, so there is not that much transfer.

Mr Cremonese: It depends on which object we are interested in from an astronomical point of view. For variable objects, the amateur can scientifically contribute to our observation and analysis of something. Even the small telescopes and small detectors that the amateurs have—there are a lot of small observatories all over Italy—are contributing to our science. If we would like to observe a comet that is a very variable object in the sky, it is not possible for a professional astronomer to get time with the telescope to continue to follow up the object. Amateurs with small telescopes can contribute to monitor the activity of an object. I wrote some papers together with amateurs putting together the data obtained by professional telescopes and by their instruments.

In some professional observatories, amateurs may use our telescopes. In such a case, they may have research that they can contribute along with the research that we are doing using other telescopes abroad.

Q255 **Stephen Metcalfe:** Can I ask about your public outreach work? I am particularly interested in how you engage with young people to encourage the next generation of astronomers to get excited about the subject and do it in a way that engages them.

Mr Cremonese: I will tell you about an event that we have had for a few years, the Astronomy Olympiad. Our national institute organises these games every year. This year, 13,000 students from 400 schools all over Italy participated in these games in astronomy. We tried to stimulate the interest of young people and young students in science. We have other events for the public, not only for students, because our observatory is open sometimes in the evening during the summer for visits to our instruments or our laboratories. Then there are several conferences of amateur groups or town halls on the last results of space missions or something similar.

Professor Thomas: We were awarded about 10 years ago a National Centre of Competence in Research called Planet S by the Swiss National Science Foundation. One of the things that these NCCRs can do is put some money aside for communications and outreach. We have a team that is available to do comms and outreach activities.

We attend exhibitions and functions such as Fantasy Basel, where we interact with younger people. Most of them are not quite school kids any more. They are involved in things like cosplay. They are also not merely interested in science fiction but in science fact as well. They pay very close attention to the exhibition that we provide there and the presentations that we do.

The other thing that we do within that comms is support a book. In Switzerland, there is a book series called Globi—the Netherlands have one called Conni—a character who goes around and does many different things, and each book is dedicated to one of the things that Globi likes to do. We recently did one of these with space, and for a time it was the best-selling book in Switzerland, which is quite remarkable. We had the vernissage—the first presentation of the book—at the technical high school in Zurich. There were 300 people in the auditorium where Globi was being presented, and Globi came in costume. The kids were shrieking—it was 100 kids shrieking, which was quite intense. It was great. We think that these types of things work quite well with the kids, and it seems to work very well.

It is a bit difficult getting into the schools. We can provide materials for the teachers, and we try to do that when we can, but we do not have infinite resources and the numbers of people to go around and do those types of things for groups of 20 or so.

As Gabriele says, trying to hit things that have an impact over a larger number of people seems to be more effective than going in individually to schools. That is not to say that you should not do it—it is an important part of what we do—but I have the feeling that it is more effective if you can find a way in which you can do it to touch a larger number of children.

Mr Cremonese: For the last three years, in high school it is mandatory to have some kind of work outside school. That could be science, technology or business. My observatory has telescopes on a mountain. We organise during the summer one or two weeks where students from high schools stay in the observatory for five days working on the telescope with astronomers. The interaction during the day and night on the telescope is exciting for the students.

Q256 **Stephen Metcalfe:** Excellent. That sounds like an absolutely fantastic opportunity, albeit one quite targeted to a relatively small number of people, which I accept is one of the challenges.

Do you do any assessment of whether your outreach work has changed any outcomes and whether it has influenced anyone to go into a STEM subject or astronomy, or whether it is just, "We've done it, ticked that box," and although they have enjoyed the experience it has not been life-changing"?

Professor Thomas: It is incredibly challenging, as you are probably aware, to try to get some estimate of the effect. In Switzerland, we look at the number of visitors who are going to the various things that we do and try to itemise that, but it is no indication of whether we have really changed their lives, which you were alluding to.

There was one statistic that I found rather unusual. In Bern, there is a lower number of students studying physics now than there was about three or four years ago. That is unusual because in the other universities in Switzerland the number has gone up very slightly. We were thinking that we must be doing something wrong, but then it struck me that maybe we had done something right—previously. It dawned on me that in 2016 we made a really big effort to publicise the comet mission Rosetta because Switzerland had a major instrument on Rosetta.

In 2019, we made a big effort to publicise the 50th anniversary of the moon landings because the University of Bern had contributed an instrument to Apollo 11. Buzz Aldrin put a Bernese experiment on the moon and brought it back again. We made a big play about this. We did indeed see a rise in the number of students who were attending Bern in physics. It is regularly one of the things that appear to be attractive about coming to Bern to study physics.

Maybe this little drop that we are now seeing is a consequence of the fact that we have not recently had a big thing that we can say, "Hey, look at this. Isn't this wow?" We have not been able to do that in the past couple of years, and as a result we are not quite getting as many students as we had.

I do not know whether that is an answer to this particular thing, but it is one of the things that we could take a look at.

Q257 **Stephen Metcalfe:** That is very helpful, thank you.

Mr Cremonese: Yes, I completely agree with Nick. It depends on the period. Just after the Rosetta mission, many people were really interested to follow conferences, to see new images, and this is reflected in the number of students for the astronomy degree. Something is changing because I have seen an increased number of students doing a degree in astronomy. The moon exploration has really stimulated interest.

A couple of months ago, a colleague and I conducted a survey of students at the end of the first period of their thesis to see whether they would be interested in a master's degree on planetary sciences, and 60% of the students were very interested. It means that all the information that we have in the newspapers and on the media about the moon exploration has had an effect on students.

Q258 **Graham Stringer:** Professor Thomas, in Switzerland what is the route, if there is a standard route, into astronomy and technology? How is that supported either by universities or the state?

Professor Thomas: We have technical high schools such as ETH Zurich and EPFL in Lausanne, and they tend to focus on the technology. I know that the central Government are quite interested in ensuring that these technical high schools develop technologies. There is an attempt to try to foster more crossover between technology development and astronomy and space sciences. This is one of the ways that I would answer this.

Universities try to do technology development, but there is a lack of getting this across into industry. Gabriele talked about patents and so on. This is true of us as well, but there are not that many of them compared with some other fields, from the experience that I have. I am not sure that entirely answered your question.

Graham Stringer: Well, I do not know what is missing from the answer.

Professor Thomas: That is fine. I will take that.

Q259 **Graham Stringer:** Is there anything you would like to add, Mr Cremonese?

Mr Cremonese: At the university, we have engineering degrees and science degrees. Sometimes, we have the same PhD students coming from engineering or astronomy, and in such a case we may start a project that involves engineers from a technology point of view and scientists from the same team and the same group. In my group, I have engineers, geologists and astronomers; the collaboration between different people with different experiences is important.

On the other hand, sometimes we may have a PhD paid by a private company. In such a case, it is more focused on some technological issue. That could be important for space instruments. The PhD student works with industry as well as with me as a scientific supervisor. This could be useful, but it is quite rare because the main problem, at least in Italy, is that big private companies are not so interested in research. They are not doing research inside industry, and this is something that is really missing for us.

Q260 **Carol Monaghan:** I am interested in diversity and inclusion. First, how successful are your countries in increasing diversity and inclusion in astronomy, and are you monitoring it in any particular way?

Professor Thomas: This is a big question in Switzerland. It is important. I will give you an example from my university. Up until just a few years ago, we had 18 physics professors. They were all male. Part of this was the consequence of the fact that many were being employed between a period of 1995 and 2005, and the sensitivity to this subject was almost non-existent.

That has changed a lot. When this group of people from the 1995 to 2005 generation, including me, retire in the next few years, there is a great deal of desire—it is not pressure but desire from all of us—to change that situation and increase diversity at the high level.

Q261 **Carol Monaghan:** That is high level. Obviously, that is important in terms of role models. What about undergraduate level?

Professor Thomas: Before I go to undergraduate, I would like to explain a little bit about PhD level if I may. We are monitoring very closely, within the scope of this National Centre of Competence in Research, in planetary sciences in Switzerland the gender balance with PhDs. Sure enough, we can recognise leaky pipelines in this very clearly. It is currently at a stage where at the moment we have 40% female PhD students. That is already on a good path. You are increasing the pool for the future.

At undergraduate level, we have done our first surveys. We have seen a couple of things and we were trying to establish a little bit better where gender imbalances are starting inside the system. We asked all our senior people who employ master's and PhD students. The students in Switzerland have to do a bachelor's thesis. It is only a small thing; it is only about five man-weeks of work, but it is the first time where they touch research. They do a master's thesis as part of their master's studies, and that of course is quite substantially more.

We looked at the gender balance at bachelor's level and master's level and asked that question. It turned out that at bachelor's level we were around 50:50. At master's level, suddenly, the number of women dropped relative to the men, and we do not know why. There is a relatively large number. These are the things that we are trying to monitor and get statistics on.

Q262 **Carol Monaghan:** It would be really interesting for you to share some of the data and statistics with us. Have you done any follow-up with the ones who have not gone on to master's level, and asked some questions?

Professor Thomas: This is very new to us. We did this study three months ago. We were really surprised, and at the moment we still do not know what to do. Following up is indeed one of the things that we should be doing, but we have not yet decided how we are going to address that.

Q263 **Carol Monaghan:** I will come to Mr Cremonese in a second, but have any particular tactics been successful in increasing diversity?

Professor Thomas: I would not say that we have used a particular tactic. We are still in a position where individual professors and supervisors choose their candidates, and we do not mess around with saying, "You will choose this particular candidate under these conditions." There is a little bit of a sensitivity in that. One thing that we notice is that female students also take a good look at the potential supervisors to see what the structure of their group is, but I would not describe that as a tactic.

Q264 **Carol Monaghan:** Mr Cremonese, how are you encouraging diversity? How successful have you been? Are there any tips you can offer on successes?

Mr Cremonese: That is not easy to answer. Since January, for the first time in 250 years, my observatory has had a director who is a woman. Something is changing. It is clear that having a female director is encouraging young researchers and other women involved in our observatory in astronomy.

The percentage of females in the national institute is about 35% or 36% and has not increased much in the last five years. The main problem is that it is not corresponding in the top-level positions. We do not have 35% of females in top-level positions. We have to correct that, for sure. It is very difficult to say how to proceed. It will take some time. We have a lot of women as new researchers, but we will have to wait some time to have these women in the top-level positions.

The gender balance among astronomy students has improved. The percentage of female students has increased with respect to the percentage that we have now in the research institutes.

Q265 **Carol Monaghan:** Are you capturing data on this in terms of trends and long-term statistics?

Mr Cremonese: Yes, in our institute there were studies and statistics a couple of years ago. Every three or four years, they improve and update the statistics in order to be updated about the number of women whom we have in the new position. In the last six years, we increased the number of researchers because we hired more than 300 researchers in our national institute, and several of these young researchers are women. The percentage is higher than in the old statistics.

Q266 **Carol Monaghan:** I was a physics teacher for many years before becoming a Member of Parliament. We have a perception of Italy being quite good in diversity. It had a different attitude towards bringing women on in science. Certainly, institutions like CERN had a good representation of female physicists. Is this just a national phenomenon in Italy, or is my perception perhaps not correct?

Mr Cremonese: No, I think you are right. Looking at participation in large international projects, there are more women from Italy. This is true. Now we are starting to see some women with important responsibilities in top-level positions. In my group, I have more women than men working on the large projects. Yes, I think you are right about that.

Carol Monaghan: We will just need to work out what your secret is. Thank you very much.

Chair: I thank Mr Cremonese and Professor Thomas for helping us with our inquiry. We go to our final oral hearing of this inquiry before we publish our report. We will be hearing from the funding council, the STFC, from the UK Space Agency and a Minister. Thank you for helping us see the international perspective. To all our witnesses this morning, thank you very much indeed.