President's Council of Advisors on Science and Technology (PCAST)
Public Meeting Transcript
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Opening Remarks

John Holdren>> Let’s call this meeting of the President's Council of Advisers on Science and Technology to order. Let me welcome the PCAST members, the senior members of the OSTP staff who work closely with PCAST and who join us for these meetings. Let me welcome as well, the members of the science and technology community at large who have joined us in the room, and I welcome as well those who are watching the webcast. It is, as always, a busy time for Science and Technology in the Administration. We have a full agenda, and the first item on that agenda is a session on science at NASA, challenges and opportunities.

Challenges and Opportunities in NASA Science

John Holdren>> We are very fortunate to have with us Dr. John Grunsfeld, who is the Associate NASA Administrator in charge of the Science Mission Directorate at NASA. He has an amazing resume, which the members of PCAST have in their books. I will just say a few words for the benefit of the wider audience. John is an astronaut, a veteran of five space shuttle flights. He logged in a total of eight space walks, more than 58 hours of space walks. I can hardly imagine that. He is affectionately known as the Hubble repairman because on one of his visits to the Hubble, he made the crucial repair that enabled the Hubble to deliver the high resolution, sharp imagery for which it is justly famous. He has degrees in physics from both MIT and the University of Chicago where he got his Ph.D., and John, it's a great pleasure to have you with us today. Often when I see you, you're in your astronaut garb. I will tell one more story. When we had the Science and Engineering Fair on the mall a couple of years ago, 1,500 different exhibits, there were two exhibits that overwhelmingly attracted the most attention from the kids. One was the robotics, hands on robotics, display and the other was the NASA tent where John Grunsfeld in full astronaut regalia was signing autographs. I think the line was 200 kids long by the time I walked by. Space obviously continues to be one of the best ways we have to inspire young people to get into science, engineering, math, and technology.

So John, it really is a pleasure to have you with us today to talk about the challenges and opportunities in NASA science. The floor is yours.

John Grunsfeld>> Well, thank you very much! I had the pleasure, on two different missions, making calls down to planet Earth that were somewhat discretionary. The first one is to call the car talk guys, which is the personal highlight of my space life career, and the other was to call President Obama, and we had a very nice conversation with him, my commander Scott Altman and myself, I was the Hubble commander. You know, he really pumped me up when he called me the Hubble repairman and he said, "Not to be confused with the Maytag repairman" and then he asked if he would check the condition of the grass at his home in Chicago which we promised to do, and we did. It is a pleasure to be here and talk about something that I really love which is the science at NASA, and folks who know me well, know I wear fun ties, I'm wearing a tie with students doing all different kinds of things and that's to remind me to talk about exactly what Dr. Holdren said, which is the importance of providing inspiration to children to study, science, math, technology, and be an inspiration to the world.

When I grew up, and I think it's pretty common for many of you as well, people were interested in dinosaurs and space. That's what inspired us and now, in today's world, it's really robots in space, and if you have robots on Mars with lasers that can zap rocks, that's absolutely the top.

What I would like to do is tell a series of very short stories today about the kinds of science that we do. Jo Handelsman got the full brief about a year or so ago, that took two and a half hours, and I'm going to do it slightly more quickly, and you know, the first is, what drives me in the morning? What is our mission? NASA is a mission agency, and I think of it in terms of these words. NASA innovates. Almost everything we do, every science spacecraft we do is unique, pushes technology, pushes state of the art, tries to do something hard. It's when you combine the technology with that need that defines innovation. We use that innovation to go explore. That's really what NASA is, our nation's exploration agency. It just happens to cover a narrow slice of what we all have which is the sun, the Earth, the planets, and the rest of the universe.

When we explore the universe, we discover things. You know, I don't know this for a fact, but I'm convinced that the drive to discover is encoded somehow in our DNA. That's why we're here. That's why there's a PCAST is because we have that drive to discover, you know, this is what makes us so successful, and when we discover things, it inspires the world.

Of course, we have to ask the question, why are we here, and why are you here, and this is a picture of Washington DC from the international space station. This is the Mall where we are right now, and NASA, Congress, and the Executive Office of the President all work together to craft our US science policy, and that includes the National Academy of Science where we are, and this is my opportunity to actually thank you. You're part of this public service that helps guide the science that our country does.

I know you're taking time from your research, your graduate students, and your families, to help serve your country, and crafting advice for the President, for the administration, for science, and I would like to thank you for that. I don't want to spend too much time. You know, the words and the endless frontier. This is actually one of my guiding document's principles is that basic research is something that really does drive the nation. It drives the economy, it drives our national security. It drives the future. You can look at today's agenda,talking about Ebola and trying to understand how viruses work. These issues are crucial and they require the kind of basic research that we all do.

NASA was started in 1958 with the Space Act, ten days later I was born, and that is sort of irrelevant, but right at the top of the list, in the National Aeronautics and Space Act of 1958 is the expansion of human knowledge of the Earth and phenomena in the atmosphere and space. At this time, there was a very lively debate going on, President Eisenhower, then President Kennedy, largely driven by Jerry Wiesner, then the President's Science Advisor on what the direction of this nation's space agency should be, and it came out of the National Advisory Council for Aeronautics. We had the launch of Sputnik, and about the time of the launch of Yuri Gagarin, the first human to orbit the Earth, the decision was leaning towards very much a human space flight focused response.

Of course, the reason was to try to ensure that our adversaries knew that our intercontinental ballistic missiles would be reliable. That's really what we were after. It didn't matter how we got at that. Jerry Wiesner argued vehemently, it should be a vibrant science program, but the space race, you know, really got caught up with the press for human space flight, President Kennedy, and his quests to land a human on the surface of the moon and return him safely. Not that he necessarily believed we would do that, but in doing that, we would achieve our goals. I think if Jerry Wiesner had been successful, we might have had a very different NASA today, but never the less, we have a really incredible NASA, and I look at the science that we're doing, the government, the taxpayer invests about $5 billion in NASA science, which is quite a significant sum. That's the account that I manage in my discipline, and then we manage another $2 million for the activity of NOAA, and there's also several hundred million dollars of science that is done for the international space station in human space flight. But I see all of this as one interconnected science enterprise. So this is the way I view the science that we do at NASA ,and it starts out with really the big bang, trying to understand the origins of the universe, primordial nuclear synthesis, how the elements that we're made out of came to be, into the first stars, galaxies, the evolution of the universe, the evolution of chemical elements, of molecules and interstellar clouds, the formation of solar systems, planets, and the proto-planetary nebulae that eventually ended up producing our Earth.

A lot of fundamental physics and chemistry went into that, photochemistry from young stars producing ultraviolet light, producing essentially all the building blocks of life in interstellar clouds, and a question about, how does it get delivered to an early Earth, I know there are people here who work on that. Ultimately leading to the question, since we are here, and we're able to ask these questions, are we alone in the universe? That is one of the driving questions and that brings me to work, and helps to stimulate me for the kind of work we do at NASA. And on the other side, to try to understand the origins of the life on Earth, biological evolution from this cosmic perspective, and how we're affecting it. And asking the other big question, is life sustainable?

Now, from a cosmologist point of view, or an astronomers point of view, the answer is no. That one we can answer. Life on Earth is not sustainable longer than a few billion years. Do I care about that? Not really, I'm thinking more of the short term. The solution to is life sustainable on planet Earth has become a multi-planet species, that makes it relatively easy.

The reason is, our sun is going to evolve, we are going to collide with Andromeda, there's lots of threats out there on longer term timescales, but we have many critical things to worry about today, and I will speak some more about that. We're divided because of accounting roles into divisions. Heliophysics,the study of the sun and the interaction of the sun's magnetosphere with the Earth's magnetosphere, Earth science, the study of the Earth and Earth systems, planetary science and astrophysics. This really is - - these are our counts bins because the last time I checked, the sun is a star and in astrophysics, we study a lot of stars. The Earth is a planet so it should be in planetary science, you know, all of these things are inter linked so again, we try to manage an integrated program of science.

So what do we actually do? Well, we fly in missions, and if I were to spend the next several hours, I might be able to get through all of the missions that we fly, but we fly these missions to answer scientific questions and to try to link the missions together to understand how systems work, not just answer individual questions, but just to give you a sense, we have 97 unique missions, 123 spacecrafts, and in the fiscal year 2013, we launch 12 high altitude balloon launches, including one that orbited the Earth, around Antarctica for 54 days, it is actually a long space mission.

We launched 19 sounding rockets up to several thousand kilometers maximum, and flew over 4400 air born hours, mostly for Earth science, some astrophysics, some heliophysics, and many of those, on unmanned aerial systems.

This is probably the most complex space program in the planet, given we're not flying a lot of the same things, for instance. We're trying to answer some fundamental questions. The origins of the sun's activity, and specifically to try to do the research which will allow us to predict variations in the space environment caused by the activity on the sun. For instance, coronal mass ejections, can we predict them before they are emergent, and how will they affect the Earth? This is over simplifying it clearly but Earth science enabled more accurate and useful environmental predictions so that includes weather, climate, natural and human induced events.

In planetary science, what drives me is the search for life. Is there life in our solar system beyond Earth? If there is life, is it independent life? If it's on Mars, there's a chance that either we're Martians or Martians are Earthlings, because of the exchange of early materials. If there's life on the ocean of the Europa, is there independent life, that is pretty far out, there's very little exchange and it probably would be. Is it like our life? Is it different? Is there any life in our solar system? And in astrophysics, trying to search out nearby habitable planets and see if anybody is home, so to speak. If there's signs of life, spectroscopically, and also, looking at the origins at the very beginning of the universe. Try to see the first stars that formed. The first black holes. The chicken and egg, was it a black hole first or massive stars that exceeded galaxies and ended up in the universe and understand the physics of the universe. I'll talk about that more later.

So how we do this to help guide our decisions is we try to draw, and Earth sciences, the classical case where Brotherton drew a diagram like this for the first time to understand the Earth's system. We try to draw equivalent diagrams for how all of the pieces are linked, and then we devise mission concepts that make sure we have balance across all of these different physics, so we understand the solar dynamo, and we understand how energy is transported to the surface of the sun, how it gets out from the sun, the role of magnetic fields, all of the various spectrums of radiation that's emitted from the sun, disturbances in the magnetic field, and how that couples through transmission from the sun to the Earth and then into the Earth's ionosphere and thermosphere, where Earth science takes over and effects climate which is sort of at the bottom.

We then do that through competitive solicitations. We put out ideas. The science community proposes, they build missions and produce the science, and so we're a little bit different than the NSF because we don't just do grants, we do contracts to build missions, and to build science and scientists and NASA together to manage these missions.

This is just sort of the connection diagram that I talked about. We actually have an electrical circuit, a plasma circuit, that connects the sun to the Earth. We are inextricably linked to the sun. And what we're seeing in our capabilities are really phenomenal. This is a movie of a coronal mass ejection taken by our solar dynamics observatory, and for the first time, we have the ability to see phenomena that are on the scale of the magnetic fields on the surface of the sun, with rocket flights, and you can see these coronal loops, the plasma is following the field lines on the sun and we're able to see things emerging and when the hot plasma comes back and hits the photosphere, you can see the heating.

This is one of the hardest problems in physics are these nonlinear plasmas and these very high magnetic fields, but it's critical to understand this if we're going to understand the problem of being able to predict solar flares, for instance, to make it relatively simple, or even to understand the solar output. Right now, the sun is incredibly quiet and that's an observational fact, but we don't know why because of the internal magnetic fields. This is an incredible computational problem. It is one of the things that exascale computing will help with. We will be power users of exascale computers when it emerges, and of course, in the late 1800s, there was something called the Carrington event, would be disastrous if it happened today, a very large event coupled to power lines and transmission lines on Earth, train telegraph stations burst into flames because of the induced currents.

This is something that OSTP helps coordinate, the thinking about. With these satellites, stereo spacecraft that are orbiting in the Earth's orbit, but not near the Earth, are able to track events from the lower corona, the photosphere of the sun, all the way to the Earth, and watching these different regimes in the solar corona, the inner heliosphere, as it goes by Venus, and as it goes by the Earth so we can track the large events.

We're about to launch an observatory, I think March is the current launch date, four spacecrafts that are going to examine magnetic reconnection. This is something that we can study in the Earth's magnetosphere, how the magnetic field lines and how opposite polarity connect, and transfers energy into the Earth's magnetosphere from the sun, and that's something we don't understand very well. We're going to be able to observe in situ, and that is something that happens throughout the cosmos. That's a problem for stellar astrophysics, for galactic magnetic fields, so something we're really looking forward to.

Of course, where the sun leaves off, we then have solar energy driving the Earth's atmosphere. I would like to say that all terrestrial weather is driven by the rotation of Earth and the sun should be a relatively simple problem, but it's not. It's just as complex and dynamic as the solar problem, and so these are the kind of building blocks of trying to understand the Earth's system. This is what was first drawn by Brotherton to provide a framework for trying to understand the Earth as a system, and of course, on the right there are human activities. Lorentz famously wrote down differential equations and said, look at the boundary conditions and solve the equations and you'll understand weather, the climate, whatever you want, and it's a straightforward problem. The issue is, we're changing the boundary conditions faster than we can understand the physics that goes into the differential equation, and the chemistry and the dynamics so it's a very hard problem.

To do that, we have a fleet of Earth observing spacecraft, most of these are competitive missions. They're selected and they have a short lifetime, 3 to 5 years by planning, but they end up lasting for sometimes decades, and provide us a long term record of environmental measurements. This is crucial to understanding the physics of what's going on, the physics, the chemistry, the dynamics of what's going on in the upper atmosphere, the atmosphere the role of clouds, aerosols, ocean circulation, ocean salinity. I will take just one vignette which is follow the water. Water is very important in getting back to things like national security. This is an important issue. I won't go through the hydrologic cycle because I was told this is a sit down event, and I can be professorial unless I am standing up. You all understand this.

Audience>> Stand up - -

John Grunsfeld>> Okay. Of those satellites that I showed you, monitoring the Earth, the ones with stars have some connection to understanding this hydrologic cycle, and this is not only important for science, but for our daily lives. We want to know, is it going to snow tomorrow? What would be the impacts of a hurricane, where would the hurricane go? What are the longer term effects, and I'll talk more about that.

We do it from a variety of ways. You think, well, we have microwave sounders and we look at the mission from drops of precipitation, and yes, we do that, but we also directly measure the mass of the water on larger scales so we can understand, what where is water stored? Where does water move, and we do that by two satellites, GRACE, Gravity Recovery And Climate Experiments,- they're flying in formation and they measure the distance between the two, and they're rather far apart. And as one satellite goes over a mass concentration on the Earth, it will accelerate a little bit more, the distance will get further and the second one catches up when it goes over the same mass, and then they're be back to the same distance. Since we can accurately, over long terms of time, weeks to months measure where things are.

So if we want to understand, for instance, sea level, now, this is a mean sea level. We can actually monitor local sea levels. The sea isn't in equilibrium as you know, there's tides, for example, and also, other longer term variances but we can do laser altimetry and measure the height of the sea. It is relatively easy to do. And we can also measure the mass of the oceans, and from this, we have seen that, over the timeframes we have had these satellites in continuity, cross correlation is key.

We have seen a steady rise of about 3.2 per year in ocean sea surface, very steady, and there's little variations. It's interesting to try to understand those but we can also measure the ocean mass. So we can differentiate between the rise of the ocean due to thermal expansion, and the rise of the ocean due to inputs, more fresh water going into the oceans, and it's critical to understand and put together the whole climate story understanding both of those.

So when I came on board, there was a big mystery. You know, I was learning about all of this ocean altimetry and I said, well, why? And if you look on the picture on the right, why is this trend so monotonic, and in the last year or so, we had five millimeters of sea level drop? And of course, certain factions of Congress picked up on this as well, and certain network television and said, see, there isn't global warming because the oceans are cooling by inference, not by measurement.

But what is really interesting is if you know where the water is, you can measure, I mean, this is a zero sum game. Either the ocean has cooled and the sea surface through expansion and contraction contracted, or the water is somewhere else. So we use the GRACE data and we found in Amazonia and Australia, they were having record floods, and we measured the amount of water sitting on the surface of the land, and we made a prediction that water will drain back into the oceans. And sure enough, it did and we're right back to the same long term trend.

It's the detective work we're able to do around the science that I think is really transformative and we need to keep doing. We also fly aircraft, I mentioned. One of them is called Ice Bridge. We have satellites that do altimetry of ice as well, and we want to compare it with what we can do with aircraft flying at low levels, and also measure the ice. But through the ice to the bedrock, and I have a short video here that hopefully will play about the West Antarctica ice shelf. I want to get right to the punch line. The entire West Antarctic ice sheet is now going to drain into the oceans and there's nothing we can do about it. No amount of carbon emission controls or anything else will stop it.

We have now reached a point that geography, that under lining bedrock will cause the entire West Antarctic ice sheet to go into the oceans, and cause a meter or two of sea level rise. That's the bad news, but the good news is it's going to take almost a thousand years for the whole thing to drain in. But the reason is the reason we know this is that we're able to measure the velocity and the acceleration of these glaciers but also the grounding line. That's the line where, as the glacier recedes, that's the line between the floating ice and the grounded ice, we have been able to track that.

Here you can see the sea ice and the grounding line, and this is the grounding line as of about 20 years ago. So they turn the floating ice to water. And then if you look at it, you know, in 2011, it will fade to that. That's where it is now. So it's backed up enough towards the continent, and the continent you have to then know, are there mountain chains underneath that, the ice is thick, and in some cases miles thick, and the answer no, they're not mountains, but valleys so sea water can get underneath the glacier, flood the valleys, that acts as a lubricant, and that will float up the shelf and it will all drain in because of the overall topography into the oceans. That's just an observation but that's what is going to happen.

We can ask the same question about the Greenland ice shelf. We have maps. This is just Greenland ice mass loss as measured by satellites and aircraft from 2003 to 2013, you can just see it tracking down. We're losing massive amounts of glacier icecap in Greenland, and there's a recent paper that says, and also, in the IPCC most recent report, if we get anywhere between1.9 and 3 degrees of global mean temperature rise, then the Greenland ice shelf will reach a critical point where it will melt before we can do anything about changing the overall temperature rise.

You know, we're basically, and our predictions, already there. Even if we were going if we were going to go to the minimal emission models. So we're talking a lot about water. What about when you don't have water? That's also a critical element of our Earth science program and what we're able to do using these water measurements. So this is the central valley of California, this is a paper, a couple of articles in a paper based on our GRACE measurements that appeared in September. So we are able to measure in the time domain the amount of water stored above the surface in lakes and river, in aquifers, and in the snowpack. So this is California over the last few years and as you know the central valley, the amount of water that has been available has been dropping precipitously. This is just a graphical way of showing that. You know, it is actually pretty dire. Now, much of this can be attributed--if you can write the differential equation, it is not that hard-- to water use. This is something we're doing. We're using water but at the same time, the snowpack is less and less each year, and this may be due to changing weather patterns, mesoclimate such as it is. And it's not just happening in California, or at least we're not just measuring it in California. We're able to measure it globally. This is just the US view, and as I said, it's happening around the world, California, and the Middle East. Talk about destabilizing the Middle East, Now, it's not about when we run out of oil, but when we run out of water and so that's in the middle panel, and then we're, you know, several billion people live in the Hindu Kush Himalaya, you know, the Himalaya glaciers are receding very rapidly, and we're seeing enormous droughts in India.

There's a lot of promises as well. We just released a climate changes impacts in the United States. Documents like this, the communication, the science, it's causing businesses to wake up and start to think about, what are the impacts to our business. When businesses wake up, they can talk to their elected officials, and then we can start to make progress, so I think there's great hope. Of course you know, we have the good story of the ozone hole and chlorofluorocarbons. I won't tell my extraterrestrial intelligence joke unless you ask me later. You know, there's hope for us. And this has been a big year for us and will be going forward. We launched the Global Precipitation Mission Core Observatory which is a partnership with Japan. We launched the Rapid Scat which is on the International Space Station already operationally doing sea surface winds. In December, we're going to launch the Cloud Aerosol Transport System, a laser system that will go up to the International Space Station. We launched the Orbiting Carbon Observatory 2. And next, we have some launches, maybe next March, we're going to launch the Soil Moisture Active Passive which is a microwave active system to measure soil moisture, a critical component of understanding, both for agriculture and understanding water flow.

Going out to the other planets in our solar system, we have spacecrafts nearly everywhere in the solar system. It's going to be very exciting. Next year for the first time, we're going to see the views of the dwarf planet Pluto as New Horizons flies over it on Bastille Day in July. It's a little harder to draw a Brotherton diagram for our solar system, but we do want to understand how our solar system formed, and where we have great detail by being able to interrogate our planets, and looking at ice top ratios and their atmospheres and their rock, compared to Earth, and compared to the sun and then compare it to XO solar systems which we now know about. I would like to say this is old style geology, comparative geology or very early biology. We're still just trying to learn about how the different planets and all of our different rocky moons and icy moons work. But it does feedback to this question of are we alone?

Now we know that Mars was once habitable. We have spacecrafts in Mercury, out to Pluto, Cassini at Saturn. We have a number of missions on Mars that you know about, Mars curiosity. We have Mars reconnaissance orbiter, we have Mars odyssey, we have the Maven mission which is understanding the loss of Mars atmosphere just arrived there. The Indians have a mission in orbit around Mars which is an incredible feat and we have strong collaborations with India both in planetary science and Earth science. The Opportunity Rover is still going after a decade, and we're working with the Europeans on two missions, in 2016 and 2018. In 2016, we're launching a geophysical monitoring station on the surface of Mars, and in 2020, we have another more capable rover which is actually going to catch samples so that someday, we're may be able to get them back to Earth. One of my predictions is that astronauts will pick them up and carry them back in the sometime in the 2040s.

I couldn't resist throwing in some pictures of (inaudible) from just a couple of days ago. This is Churyumov Gerasimenko 67P Rosetta spacecraft orbiting took these images, they picked a landing site and the Philae Lander landed on Wednesday. This is something we had some participate. It's a little dark but it's really far, it is 510 million kilometers away. Any ways, it is an orbiter and a lander, the lander separated, took seven hours to free fall. The (inaudible) is not very big for these guys. We were actually able to see the picture on the left is an image from the Rosetta camera looking at the Philae Lander on its way down. It landed, it bounced, it floated for about two hours, and then miraculously just landed on its legs again. It is a tripod system. Bounced again and landed and then we got pictures. Unfortunately it's on a steep slope, we know that, it has 60 hours of battery life and a small solar array and hopefully will allow it recharge some batteries to get us about six months of life. This is a European space agency mission, and they're leading it. I think one of the key characteristics of good leadership here with is to be a good follower. They invited us on board. They have four instruments. They are the primary players. This was an incredible feet for the European space agencies to be able to do this. This is a very complex mission. I'm very happy to be a minor partner on this team but you know, they landed intentionally when the comet was far away because hopefully Philae and Rosetta they can watch the comet as it comes in and starts becoming active and starts having a sublimation of the ices and the volatiles into gas and then measure those. For humanity, this is really the first time we have landed on a piece of the solar system as it was before the sun formed, or around that time, four and a half, 5 billion years ago. It looks like a piece of really burnt toast, and it has things like hydrogen isocyanine, and hydrogen cyanide- - you know, all kinds of organics, carbon monoxide and who knows what we are going to find. We have mass specs on board. This is just showing a graphic from the European space agency where it first touched down and where we think it might be. The comet rotates once every 12.4 hours, so when it bounced, the comet continued to rotate under it, so we think that's where it landed. This is just an image of where the primary landing spot was. Tough environment, a lot of boulders, you know, this is kind of brutal, we provided a lot of support to ESA. It's a great partnership, it has roughly 90 percent roughly of our science missions are done with international partnerships, and these are just the four instruments that NASA contributed.

There's lots of participation on the teams. On Mars, this is the famous curiosity selfie, taken by the camera on the robotic arm, moving around and then stitching it together so that the arm disappears but Mars has turned out to be an incredible place. The goal of this mission, we call it the Level One requirement or the main requirement is to land successfully on the surface and find out if the environment of Mars was ever habitable, meaning liquid water on the surface that might have lasted a long time, that wasn't too alkaline, that wasn't too acid, didn't have weird minerals that might have been toxic for life. We landed and we looked around and said, we're in a dry river bed. The geologists knew it instantly. This looks like analogs on Earth. It has a lot of clays, sulfates, carbonates. There was a fresh water river flowing through there. You can see a river delta. Some time ago, probably about 3 billion years ago, Mars looked like Earth. It had snow cap peeks, it had clouds, it had a hydrology cycle, and fresh water lakes with relatively neutral PH. You could drink it. Bacteria if they were there could drink it. So within the first two weeks we answered the question, Mars was once habitable. We don't know what happened, Maven might help us, but the good news is all the way up Mount Sharp are sedimentary rocks. So we are going to be able to interrogate the history, just like going through the Grand Canyon, Hopefully instead of just a billion or so years, we can do 3 billion years and interrogate the rock record to see what happened? Was there some cataclysmic event where Mars' atmosphere was stripped off, a solar event, an asteroid, who knows. We're going to figure that out. Or is it just the slow evaporation of water. Hydrogen gets stripped off preferentially, and we see this in the deuterium to hydrogen ratio. The deuterium is enhanced, so we know that hydrogen is getting stripped off and water is getting stripped off.

The Maven mission is now measuring that in situ. We preferentially can see hydrogen getting stripped off. So we have been driving. We have done about nine kilometers, something that, you know, any reasonable geologist would do in a day has taken us a little over two years. That's the disadvantage of having a roves on Mars and not having a geologist on Mars. Here is a view from just a couple of days ago. This looks like west Texas for those who live in Texas. There's a good reason for that. Here's another view.

Sand dunes, we have learned not to drive on sand dunes because you can get stuck. There's really sharp rocks. We have been driving over sharp rocks and we are tearing up the wheels. Our plan is to drive up Mount Sharp, interrogate the rocks, drill cores, do mass spectroscopy, zap rocks with lasers and look at the elemental abundances, and we're hoping to get up through this hemotype ridge which is the mineral containing iron, formed in the presence of water, up to the sulfate units, and try to figure out what happened to Mars. There is a lot of water on Mars today, it is under the ground. It is an ice sheet. We know that. Phoenix landed on it about a decade ago. We were looking for water. The thrusters blew dust off. We landed on a glacier, a water ice glacier, so a lot of water on Mars today. Another planetary body, it is a moon of Jupiter, Europa, and it also has a lot of water. This is an image from Galileo. Almost everything we know about Europa comes from 12 orbits, almost 20 years ago and when we learned from the gravity measurements, of the acceleration of the spacecraft, the surface observations, is that Europa is something about the size of our moon and it has a rocky core, a mantle, it has a thick 30 - 50 kilometer salty ocean, we know this because of the currents, and it's conductive, and thin a thin 5 to 10 to 20 kilometer ice shell. And it probably has been like that for 4 1/2 billion years.

So the question is, if you have a warm salty ocean, if you have organics because the solar system formed with all of these organics, and you have energy sources, both chemistry and geo thermal, or Europa-thermal, caused by tidal flexing of the core, is that the right condition to form life? Well, we think on EEarth it is, but there's a lot of other questions, chemistry, concentrations, and all kinds of things.

Dan and I have just recently had an interesting conversation about this, but the cool thing is we can go there and find out. That is the neat thing about planetary science. So even more so, I had to bring Hubble into this story, recently observed the possible presence of plumes of hydrogen and oxygen, ionized, in the ultraviolet, primarily water that got photo-disassociated that represents a plume of water, 200 kilometers high coming from the south pole of Mars. This is expected by models because of the tidal flexing and the eccentricity of the orbit. We see this with Cassini spacecraft on Enceladus which is very similar. So we're planning to a mission sometime in the 2020s, and it is still in the preplanning stage, we're hoping to get it in, to the next budget cycle as a new start. There's a particular Republican somewhat tea party leaning congressman, John Colberson from central Houston who is passionate about this. What a great thing to have these advocates in Congress.

He wants to find out if there's life on Europa. If these plumes are validated, the Hubble observations trying to validate them, we could fly through, with a small satellite, something like a cubesat, through the plumes and collect some ice. Melt it and see if there's anything swimming in it. It could be as simple as that. Of course, that's not really easy to do when you're traveling at four kilometers per second or so around a planet, and the plumes are coming out at high velocity. But we're looking at that.

Another mission that's very exciting related to Rosetta, is we're going to go to the asteroid Bennu so it is about 500 meters across and crosses the Earth's orbit frequently.

It is I would call a potentially hazardous asteroid. I would say on a billion years, two billion year time scale, it probably will hit the Earth, at least high probability. A very low probability in the next few thousand years based on the measurements. We're sending a spacecraft there that is going to orbit, launching in 2016, orbit, characterize it down to millimeter scales, characterize it spectroscopically, minerallogically,and find a landing spot, land on it briefly, grab some samples up to a couple of kilograms and carry that back to EEarth. So we're going to get pristine samples from this asteroid. This is part of a broader asteroid initiative that is being done across the agency.

Of course, there's the rest of the universe, and, I apologize it is a pretty bright room. That is the horsehead nebula in the infrared. In astrophysics, we try to start with cosmology, the big bang and end up with the conditions on Earth for the origin and evolution of life. Of course, I have to show at least one picture of me floating around on the Hubble, installing the wide field camera three, which has allowed us to take images of this Hubble ultra deep field. This is an image that has lots of stars in it but not in our galaxy. It's looking past our galaxy. In this image, if you could see it, and you know, I gave the pitch so it's available to you and many of you know this. This is the deepest view of our universe. There's a galaxy in this picture, that the light was emitted 13.2 billion years ago, about 500 million years after the big bang. It's very red! It's just a few pixels but we're able to identify it by its color that it's that distance. Everything else in this is a galaxy with 50 to 200 billion stars. You know, there's almost an (inaudible) number of planets in this picture, and of course, last weekend Brian Schmidt, Adam Reiss, and Saul Perlmutter won the 2015 Break Through prize in physics and in 2011 won the Noble Prize in physics based on using the Hubble advance camera for surveys, the one I repaired in 2009, confirming the existence of cosmic acceleration from which we infer there is this mysterious thing called dark energy, which we know almost nothing about and I think this is one of those Copernican moments when you have to sit back and say, in the hay day of astronomy, the hay day of Hale and Edwin Hubble, we thought we were pretty smart. We discovered an expanding universe. Everything we saw back then, all of the stars and galaxies, all of the gas clouds, you know, the inference of gas between galaxies, even up to the time of cosmic structure being discovered and gas between galaxies, we thought we had a pretty good understanding of what the universe was made out of.

It turns out everything we can see, accounts for two percent of the known universe. Another two percent is matter like us, protons that we can't see. Roughly, you know, 25 percent is dark matter which we really don't know what it is, and 71 percent is dark energy, the energy content contained in this cosmic pressure. We have absolutely no clue what that is. So we live at a time when 96ish percent of the universe is composed of things and physics of which we know nothing about.

So it's a pretty exciting time to be a physicist if you ask me. Next year we are celebrating the Hubble 25. So I just wanted to debut a 30 second video.

(MUSIC from video playing)

So we are kicking off a celebration, in fact, today, after the release of this video, the Hubble 25 celebration. And that was me at the end.

That was the last touch of Hubble. There was a second last hug of Hubble, but that's another story. But I saluted Hubble and inside of my space suit, and I haven't actually gone back to the tapes, but I said, you're the man. We actually have to anthropomorphize these telescopes. The Hubble is the people's telescope. People just fall in love with Hubble. They follow its life. Now they're doing it with curiosity. The Rover which is a "she", she has a twitter account and a Facebook page, but we're looking forwards to the future. The James Webb space telescope, it's going to go where no Hubble has gone before because it is inherently infrared telescope. It picks up at about 8 microns to and goes up to mid-20s microns, and it is going to able to see, I mentioned that the earliest galaxy was very red. It's just because light gets stretched out as the universe expands, so anything more distant than Hubble can see is in the infrared, so ultraviolet at 200 million years old in our universe is now infrared. So we need an infrared telescope.

So JWST is going to look at the first stars and galaxies if we can because, as the universe cooled, electrons combined with protons to create neutral hydrogen, the universe became opaque, and it wasn't until the first stars turned on and produced ultraviolet light, we think that the universe became re-ionized, and transparent again, and at some point, we might be able to see the moments when the universe suddenly started to emerge and become visible. The first galaxy, the first stars, maybe the first black holes. This is going to be amazing for science!

We're also going to have to peer into these dense clouds of dust where planets are forming and see them in the process of formation because the infrared light can sneak through these micron sized cold dust grains, and of course also look at exo-planets. When the James Webb space telescope was conceived and designed, it was pre the discovery of the first exo-planet around a nearby star. But these planets pass in front of their host stars in some cases, and we can do differential spectroscopy, the spectrum through the atmosphere of the planet, and also direct spectroscopy from the reflected light, and try to understand what these planets arelike . Here is just an example of the James Webb space telescope from 25 transits of something like a Neptune around its host star and if there's water, if there is methane, we'll be able to see spectral signatures, and at 15 light years, there's very high signal to noise. This is really amazing and if we're really lucky, and there's something like a super Earth, a couple of times the mass of the Earth within 15 light years, we may be able to get a spectrum of its atmosphere. We have all the optics complete. It is at the Goddard Space Flight Center. There's a web cam if you want to watch it live in the clean room. All of the instruments are here. They have been tested together. We're building a spacecraft. There is huge tennis court size sun shield because this telescope is going a million miles away and Earth's sun (inaudible) .2, and the sun shield is going to protect the telescope from the sun, and it will cool to 40 Kelvin.

Eric Lander>> John, you have to leave us ten minutes for Q and A, which means you have about another 30 seconds.

John Grunsfeld>> I will just flip through to show Kepler has been discovering lots of planets, and most of them turned out to be Earth size, and we have a good plan for astrophysics including a telescope that's going to find all of the near exo-planets and go beyond.

So let me flip through to the international space station. We are doing a lot of research. It is actually the subject of a whole another talk, Outside it is mostly about Earth science and astrophysics, and we're working together with mission directorates to try and come up with a good Mars plan going forward. I would like to do one more slide after this, but there's a metric that Greg Davidson, who works for Northrup Grumman, put together and looks at Science News. How many of you are familiar with the magazine Science News? I have been getting it since I was a little kid, and he just tracks the stories by agency, by topic by division within an agency, puhsing at every which way he can to generate metrics. So he sent me the metrics for NASA Science Mission Directorate, and it is just a current of articles in science news referring to peer review papers or talks given at public meetings like American Astronomical Society for instance. And it includes NIH and everybody else, and in 2013, SMD accounted for 15 percent of all of the stories reported in Science News which is pretty phenomenal. It was a good year. I'll just close on this, which is I talked about closing up, managing the ozone hole and chlorofluorcarbons as the hope. I think this is really our hope for the future. Our young scientists, and these are the future decision makers, and the STEM issue is very important, and the President's initiative for getting one million students into STEM fields over ten years, 100,000 master teachers, absolutely important. There's another 99 percent of Americans, that we reach with NASA and NASA science that we inspire, that are future parents, future leaders of business, future legislatures, and we need more scientists in Congress, certainly.

I will just mention this image is of two young people in the microbiology lab at NASA Johnson space center. They're working with a relatively harmless e coli, it was relatively harmless when we bought it, ATCC 25922, and the girl there, on the left, asked the question, can e coli become resistant to triclosan? There had been a paper in Nature that said that, and be she wanted to test that, and there was a lot of papers that said no. And amazingly, she cultured these e coli in little filter paper, put the triclosan in and tried it in various concentrations, and found in the very first run, the very first run that there's colonies in the exclusion zone. So the triclosan goes out to the nutrient agar, kills most of the bacteria, but there's little spots of colonies growing where at the first try were resistant to the triclosan. She took that and recultured it and found out that in fact, all of its descendants were resistant to triclosan, and this is why we had to go to the NASA Microbiology lab. She then took it the following year and asked, in developing resistance to triclosan, which is what we're putting in soap and flushing into sewers, and everywhere else. Did it inherit resistance to any other microbials, to tetracycline and penicillin based antibiotics, and in fact, it did. By applying resistance to triclosan, it's also resistant to other common antibiotics. A very scary thing. This is my daughter, and she is at MIT now, she didn't make it into your biology class, she is in the other general biology class, but I'm very proud of her.

You know, I'm close with that.

(APPLAUSE)

John Holdren>> All right, we have now seven minutes for questions. Bill Press was the first flag up. I was the second. Bill, there you go.

William Press>> Thanks, John for that last anecdote. That was very wonderful. You are someone who has lived the two cultures, the explorer culture, of human space flight and the discovery culture of the science side and of course, the repair of the Hubble was in some common sense, proof that these cultures had something to contribute to each other. More recently, what do you see as the synergies between the human space flight and scientific discovery?

John Grunsfeld>> I have two answers for that. One is research on the international space station. Having a scientist in space with a scientific insight or an engineer in space with an engineering insight, is really the key to making progress in a lot of areas. It's a simple thing. If you take a bag of goldfish to space and you eat the goldfish and crumbs are left over, someone who doesn't have the kind of curious mind that we all have, will take the bag and put it in the trash to be burned up on reentry, and a good scientist is going to look at it and see a granular system. And how all those crumbs are floating around, and how, either through electrostatics, or if it were really in a vacuum, by inference Van der Waals forces and other things , how they start to aggregate and see a planetary system in formation. And it might be that insight that leads then to a research project that might solve a fundamental problem. Simple granular systems, is one of these fundamental condensed matter issues we never seem able to solve.

The other is if you are following a procedure for a very complex experiment, it doesn't work. Is it because the equipment wasn't designed very well for space. Is it because it's broken, or is it because we're about to get some new insight into the way things work in the absence of gravity. So I think there's enormous opportunity to make real progress in a number of scientific fields through our investments in the international space station. The other is, if we have human is in freefall for six months which is approximately the cruise time to Mars, so we're actually doing the experiment, cruise to Mars, other than radiation. So this is, something we haven't advertised but for the most part, we've solved the problems of muscle and bone loss in space through the international space station. It's very complex story, and it would take me at least 20 minutes to describe the whole deal, but I'll whisper to you the answer. Diet and exercise. (Laughing) That's absolutely true. Once we started looking at real nutrition, vitamin D, you're never going to build bone without vitamin D. We learned that in the 1920s, but it took the space program a little longer to relearn it in space. You also won't have strong bones and muscle unless you flex them, that's what gravity does for us. And the combination - we have crew members coming back very strong. We're learning that, and I think the next step is to put humans on the surface of the Mars to be astrobiologists and geologists.

John Holdren>> This was an extraordinary presentation, and you covered an enormous amount of fascinating topics. One of the most fascinating I think for many people is the search for extraterrestrial life. You touched on that in a number of points in the talk, and an aspect of that, that I find interesting, I think a number of other folks do as well, is the question of potential contamination of life elsewhere with organisms that traveled on our spacecraft from Earth, or the reverse problem, contamination of the Earth from returning samples that contain organisms that originated elsewhere.

I think this falls under the heading of planetary protection, what we do to try to avoid that. I think most of us suspect that these are very low probability risks, but nonetheless, ones that need to be addressed. Do you feel that we're on top of that in the kinds of missions that you were describing? Are we taking an appropriate level of precaution in both directions?

John Grunsfeld>> So obviously there's a multi-factorial question. The first question is forward contamination to Mars, and I think we have a pretty good handle on that because the surface of Mars between radiation, ultraviolet cosmic rays, and the dry environment, is extraordinarily hostile to life, and we do have standards of cleaning spacecraft to get them to a low level of contamination for forward contamination.

A more subtle question is, if you're going to Mars to try to detect organic molecules that might be indicators of life on Mars, past or present, what you don't want to do is carry those molecules with you, detect them, and then make some grand claim ,and it's very hard not to carry those things to Mars, so you have to specify levels and what organic molecules, aromatic hydrocarbons,or all kinds of the things that are used routinely in preparing the spacecraft, and especially for potential Mars sample return. We don't want to go to the expense of sending a spacecraft to Mars, core some samples, put them in sample holders, bring them back, only to discover Earth life that we took with us and brought back. I would say we have a handle on it, but it's a very hard question because there's a lot of molecules on Earth. and we don't know what we'll find on Mars. So we have standard and we're working that and we have a planetary protection officer, Cass Connelly who is here, and a team of scientists who work on this very problem to come up with those standards. A more difficult asked question is, as soon as we send people to Mars, which I believe we will, meaning leave planet Earth, the whole forward contamination problem is basically solved for a different reason. People are dirty. So the reverse one, I don't think we have a good handle on. My claim is, by far and away, the most dangerous planet in the solar system for people is Earth. We know that. Life is tuned to try and kill us. It is amazing we survive at all, we see that on a routine basis. We are doing danger to our environment which is making it hostile for human life on Earth, and much of other life in terms of biodiversity.

Again, this is hope for that. What do you do if you send a crew of four people to Mars and they come back and they have a cold, do you let them come back if you don't know? It's a very tricky question. That one, I think, fortunately is decades off but one we need to answer.

John Holdren>> You have exhausted time, and not just the subject but we need to move on to our next topic but again, that's a spectacular presentation. Thank you so much!

(APPLAUSE)

John Grunsfeld>> I'll stick around if anybody has questions during the break. Thanks very much!

John Holdren>> Well, I think Eric Lander is going to chair the next session.

Eric Lander>> I will just add, You said in the beginning and as you reflect on your ties, inspiring people is an important part of all of this, boy you have accomplished the mission and it's great that we have this on the web for people to see, but thank you for sharing that.

Corporate Investments in BRAIN Initiative

Eric Lander>> So we move from the incredible inspiration of space which I think we all grew up with, to one of the other great inspirations of the inner space of the brain, to still largely uncharted territories. If we don't know 96% of the universe out there, the fraction of what we don't know about the human brain is probably greater than that.

And so it's fitting that we have a second panel here related to the BRAIN initiative which has been an exciting scientific initiative that has come together over the course of the past couple of years has been an initiative started by this administration but I think has captured the imagination of the scientific community perhaps in much the same way as space has. And less known than the NIH grants that might be given and other agency grants that might be given is the fact that there's a lot of really interesting corporate investment related to the BRAIN initiative.

I can't help but telling that maybe 30 years ago, I visited Bell Labs and was walking through andprobably one initiative which has been an exciting scientific initiative that has come together over the course of the past couple of years has been an initiative starting neurobiology. And somebody looked at me completely seriously and said, we have always considered the nervous system part of the Bell system, an exciting scientific initiative that has come together over the course of the past couple of years. In any case, I'm therefore very interested to hear about corporate research into the brain and thus corporate investments in the BRAIN initiative. We have three wonderful speakers here for our panel today. Thomas M. Baer, the Executive Director, Stanford Photonics Research Center, Kristoffer Famm, Head of Bioelectronics Research at GlaxoSmithKline and Robert Wells, Executive Director for Strategy at Healthymagination, at GE. I'm not sure what order you guys want to go in…have you got a plan? We're going left to right…Wells

Robert Wells>> well thank you very much Dr. Lander. It's great to be here with the members of the committee this morning. I have to say it was, especially powerful to come in at the end of the presentation because I remember at a tender young age being in summer camp in 1969 watching on a black and white television in the hills of North Carolina and that's back when they used to put tinfoil on the antenna to make it pick up better and watching Neil Armstrong stepping off on the moon saying one small step for man, and one large leap for mankind.

Thank you very much Dr. Lander. It's great to be here with the members of the committee this morning. I have to say it was especially powerful to come in at the end, thestory has a wonderful way of repeating itself and I think in my lifetime, there will be an equally powerful moment or moments in science where we look back and we remember where we were when ___, and we can fill in the blank with a number of different areas of understanding the brain, where I think that will prove to be the case.

We're very excited about the work we have been doing in GE in the brain space. In one sense, we have been doing it for more than 100 years because we have a reputation as the company that invented X-ray technology and imagery, which is enormously important, vital to understanding the brain and the new advances in MRI technology in CAT scan, PET scan, and all of these things that help us visualize in rather unprecedented ways now, the way in which the brain operates. We not only at GE but other companies, who are working on technologies that allow you to visually enter, quote unquote, enter the brain and to see this amazing circuitry that takes place inside of the brain and it's very exciting for us to be part of that, both to develop our own technology and but also to work in concert with our partners.

That's really several of the things I want to talk about for just a few moments this morning in the panel, which is to talk about some of the efforts that we have underway to highlight sort of how diverse they are. The things that GE has been doing are not just in one dimension but in a number of other dimensions that we think are relevant to this fantastic work in neuroscience and to the President's BRAIN initiative as it's been going on for the last 18 months and also, I should say, to a greater global effort like projects like the European brain project as well.

What we see when we look across the world is a great opportunity. There's a lot of response in the brain space because people look at neurodegenerative disease and challenges in that and they realize what an incredible challenge that is for societies around the world whether you're talking about dementia and the toll it takes on patients and the caregivers who take care of them or whether it's taking care of our servicemen and women who come back with PTSD and traumatic brain injury.

I think there's an upside there, not just taking care of those conditions in those patients but thinking about the neuro-space as a real engine for economic innovation, as a real engine for societal innovation in a very positive way.

All of that is what we have been seeing in the last year, plus, that I have been part of GE and a part of this initiative.

So under our health imagination team, our company has been working to convene the traumatic brain injury community through the GE NFL Under Armor initiative, and this is a $60 million open innovation challenge to develop next generation imaging technology and algorithms, and to also provide better devices and gear for brain protection.

GE has also supported and been involved in a very interesting grant from the defense department, the TBI in points initiative, which is a program that brings together multiple academic leaders in the TBI field to better understand, diagnose and treat TBI. We should also say we have been very involved in the public policy world and Tom Kalil and I were at a meeting this morning at a meeting we call our brain trust series where we brought together a number of leaders in the field, academic admissions, clinicians, patient advocates, foundations to deal with some of these issues that are gating factors or, I would say unrecognized opportunities that we can work together in a more collaborative and cohesive way to move the field forward.

Our Global Research Center, that you mentioned a minute ago about being at Bell Labs. There's not a whole lot of corporate big R&D centers left anymore, but we're proud we do have one of them, our Global Research Center which is a multi-country presence, but is really head quartered out of Albany, New York. And we have a number of efforts there not just to advance our technology that you're probably more familiar with, the MRIs, and the CATs, and the PET scanning but also, to work across life sciences with a number of partners and in the recent grants that was announced by the NIH, as part of the brain initiative, GE was part of one of the grants with West Virginia University, but a partner on a number of other applications, I think 6 or 7 of them or at least all six of the different areas that the NIH had delineated as being priorities.

We have a corporate venture investing business and like corporate venture funds, we look at not just opportunities inside of GE but those high-growth silicon valley opportunity companies and in this particular space and perhaps we can talk about this more in the Q and A later, this space of the brain is particularly a hot area for young companies, for spin off companies from places like MIT or UCSF and those technologies and bringing them down field so we're very interested as an investor as well as a technology developer. And finally, just continuing work at our healthcare group to bring these technologies into the commercial forefront.

We are constantly evolving our MRI technologies, our CAT scan technologies and PET technologies and all of the products that go with those. I wanted to keep my remarks brief and concentrate on the Q and A time and talking about the specifics but I want to give you a sense of the broad area that we have been working at in GE and will continue to work in.

We think that the BRAIN initiative has been enormously useful as a policy tool. It sets a framework on how it applies to the external environment and I think that's important in a large company where you're trying to make a lot of decisions about investment, decisions about prioritization, to know there's a baseline of policy support which goes with that, I think is enormously useful.

We are delighted with it and also delighted work with our colleagues in Europe and elsewhere as this issue as neuroscience becomes such a priority in so many places. So let me leave it at that and answer the questions in a few minutes, thank you!

Kriss Famm>> Thank you, my name is Kriss Famm. I come from a major health care company predominantly focused on pharmaceuticals, vaccines, and consumer health products. I'm going to be talking about the health products but we've also made a foray into neuro technology, in the last couple of years which, I will talk about here.

So we have entered the state of neuro technology which I would explain how it's intimately linked to the brain initiative. We have a vision to open up a new therapeutic modality, a new way to interface with biology for treatment effect. Small or large molecules which is the bread and butter of a company like ours is obviously tapped into control systems in biology that exist and therefore have been incredibly successful for many different treatments to have an effect on biology. The nervous system has that potential. It is a controlled system that affects a lot of things in our bodies and that isn't limited to the brain. It's controlled by the brain but the nervous system crisscrosses our entire body and virtually every organ is innovated and these, of course, are the organs that are at the epicenter of many chronic diseases. This ranges from cardio vascular conditions such as hypertension and rheumatoid to arthritis and metabolic conditions like diabetes, respiratory conditions like asthma and the list goes on.

We - - this is where the GSK effort is slightly different from much of the policies of the BRAIN initiative. We are focused on doing the therapeutic innovation, not just in the brain but in the periphery. The brain research is of course critical. It is the biggest scientific challenge, arguably of the century and it will provide us an understanding of neural circuits and the innovative technology, the tools to interface with precision in the nervous system.

However, we believe and I think this is an important point of potential discussion that early and substantial translation into medicine will be in the periphery or that technology. All nerves that are close to the visceral organs, there the complexity is lower, it's still complicated but the hundreds or thousands of nerve fibers that go to my spleen or pancreas is a more contained problem then the 10 to 11 neurons that I hopefully have in my brain - - and animal models clinical end points and so on lays a path for what we believe clinical translation in the sort of diseases that I mentioned before and this is where we need to get the right interconnect if you will, between the brain initiative and the advances that are made there in terms of technologies and the translation into treatments for the sort of organs that I described before.

I want to give you just a couple of quick examples of the potential here, just to give you some clinical evidence that the nervous system can control disease.

One classical example and one that is more recent, In terms of hemodynamics, hypertension is a disease that for a while we know can be controlled by the nervous system this is preclinical data from a dog study that’s shown by stimulating on the bare receptor, a certain nerve that comes from a region on our carotid artery and detects pressure in the vasculature, sends signals to the brain, if you stimulate on that nerve you can suppress hypertension, a drop in 20-30 milliliters mercury here. And there’s a pivotal clinical trial that's being run currently in patients that are not controllable well with molecular drugs and its showing great promise.

An area that is more recent and with the clinical information that's coming out now, is around the nervous system control of inflammation and the immune system . This might seem surprising to many of us who grew up with cell biology and understanding the immune system is an independent system, it turns out that the nervous system can act as a brake or accelerator in many immune inflammatory processes. In this case, it's been shown solidly in preclinical work that signals from the brain, down the Vegas nerve to splenic nerve to the spleen can set the level of proinflammatory cytocam reduction of cells in the spleen and the first clinical data came out a couple of years ago. It’s shown here, it’s only 8 patients.

This is typically way too early for a company as large as ours to talk about data of just 8 patients but just to give PCAST a flavor of what I think may be coming here, six out of eight patients who had late stage rheumatoid arthritis, when they had neuro stimulation, got suppression of their disease down to a level that's typically achieved today with anti-TNF and other biological drugs. It's quite a substantial effect through neuro modulation.

Now, our ambition as a company and I think it speaks to the potential here, it's rather revolutionary rather than evolutionary. We want to get to a device space where we have miniature devices that can detect underlying neuro signals, the codes that go to and from these organs and identify the key signatures there and then in a closed loop fashion control those signals to restore health in organs. And this is an artist’s impression of what it could look like. Another important aspect here of course is miniaturization. We need to get to a form factor that allows implants in type 2 diabetics around the world, that's not going to be done with the pacemaker sized modulators that we typically see today. So this is an area where biology and neuro science and technology advances have to be hand in hand.

I would like to say a few words about what we're doing at GSK, together with a broader research community and particularly the academic community here in the U.S., and funding bodies here in the US. We as a company have backed a growing network of academic institutions around the world to try to get proof of principle for both disease intervention and technologies in this space. We work with 40 or so groups at the moment looking at 16 major chronic diseases and looking at a number of different ways to interface with those visceral nerves. A lot of this work builds on technology advances for the brain, takes it to these small peripheral nerves and seeks to basically read write and erase signals in those nerves.

We have also launched a bioelectronic medicines dedicated venture fund, $50 million venture fund, investing in pioneering companies in this space, as well as technology companies that have enabling platforms for these sort of medicines and maybe important for this discussion, We have tried to be a constructive partner in putting the spotlight on opportunity here so we sort of get this foundation and research which we believe is critical to activate a field like bioeloctronic medicines. We have published a research manifesto and more importantly a road map for foundation of the research with a number of academic leaders in the space and have tried to work constructually here with NIH and DARPA as they have chiseled out their really quite strategic programs called spark and electrix respectively. This is a program to really map the innovation of visceral organs. This is a map on which we can build these sort of devices with lots of parallels to the genomic map on which we can build molecular interventions.

electrix is a DARPA program looking to make really miniaturized smart implants on peripheral nerves with the aim of them being injection sized here and finally, and this is what drove us to the White House BRAIN initiative conference a month and a half ago where we announced a new funding program, we have launched what we call an innovation challenge, basically a prize for generating a preclinical research platform to read, write, and erase neuro signals. This is so that it can work in rodent clinical models. This is critical and a gap at the moment. We are looking at chronic diseases but can really only do acute experiments. There's a contradiction there where we need to be able to follow neuro signals over time and modulate them over time. In addition to that $1 million prize we announced a $5 million fund for academic teams and small companies who want to go after this.

So why did we want to launch that at the BRAIN initiative conference? Well that is of course because the same technology that is applied to the brain will open up to other signals in the periphery and the circuit is really understood when you understand both the brain and the affecter side. I think that exemplifies how I hope bioelectronic medicines can be an important translational outlet on the brain initiative --thank you.

Thomas Baer>> Thank you, I would like to congratulate both PCAST and OSTP for support of the BRAIN initiative and neuroscience research in general. I find this to be one of the most interesting areas of science and just as federal funding has allowed NASA to be the premier organization for exploring outer space, I believe that funding of the brain project is going to allow the United States to be the leader in exploring what I think is the most exciting frontier of inner space.

So as mentioned, I am the director of the Stanford Photonics Research Center and have been working with a number of scientific societies known as the National Photonics initiative. Just to start off with, photonics is basic the science and technology of light. To me, it's remarkable how much this science and technology supports both the exploration of the outer space through the web, and Hubble telescope, as well as technology that's absolutely critical for brain research in terms of involving sheet microscopy involving two protons sources, et cetera.

My support of the brain project came out of the national academy report called the optics and Photonics, essential technologies for our nation. Which recommended the formation of a national photonics initiative and the purpose of this is really to bring together industry academia and government to identify advance areas of Photonics that are critical to US competitiveness and national security. The societies are listed here and they are the leading scientific and engineering societies supporting photonics research within the United States and we represent about 150 thousand researchers around the country. The areas we decided to focus on are five areas as we have identified as the highest economic impact areas and of course, one is in the bio medical area. And in discussions with federal funding agencies and

OSTP we decided to focus primarily within the bio medical area on the topic of neuroscience and the brain initiative in support of the brain initiative. What we then was, talk to companies that have a strong interaction and formed what we call the Photonics industry neuro science group, and those companies are represented here. It is remarkable to me that some of these companies only had 2 or 3 employees and had start-ups in the last year or two all the way up to multibillion dollar company.

All with active interest in supporting the brain initiative, R&D investments, they're going to make in collaborative arrangements that we are helping to facilitate. So what we have done is focused on the NIH initiative, the BRAIN initiative goals have been defined by the NIH working group and this is listed here and they involve generated circuit diagrams of the brain producing a dynamic picture of how the brain functions and then linking those dynamic activities of the brain to behavioral changes and then developing innovative technologies to understand the human brain and treat its disorders.

So these are four of the seven areas of focus identified by the NIH working group and all four of these areas are primary and critically dependent on Photonics technologies. This is a very interesting analogy to how you go about looking at and studying an unknown integrated circuit or electronic circuit. Well, first of all, you want to map out where the connections were located within the integrated circuit and make it visible and once you have it mapped out, you want to see how it functions. You want to turn it on and take a look at it and see how it measures the signals within the integrated circuit. And finally to probe that circuit with signals, to see if you really do understand its function and then you want to do something useful with that circuit and really those four NIH goals follow this analogy about how you would go about looking at an unknown electronic circuit and they apply it to looking at the function and dynamics of the brain.

So just like an integrated circuit that’s covered with epoxy, the brain is not transparent to light. It is opaque. It has a lot of scattering fat bodies within the brain. Over the last 2 to 3 years, people have found very innovative ways to clarify the brain yet maintain the structure of its neural interconnect. That's indicated here on the right side there. It's the same brain that’s on the left side but it's now been clarified using a process that was developed by Karl Deisseroth called clarity which electrophoretically separates out the scattering portions of the brain and leaves the neurostructure intact.

Using this and using genetic engineering to light up the circuitry within the brain, we now have complex pictures and maps of the brains at resolutions that have never been achieved at this level within this size of a brain so we can now look at essentially, a whole mouse brain and map the electronic circuits within it.

The technologies that are used to do this are fundamentally molecular biology technologies that genetically program the neurons to express florescent proteins and then new designs of microscopes that are called light sheet microscopes indicated schematically here. These microscopes were developed by leading research labs at genilia farms and other places, MIT and at Stanford and these are the diagrams that when you look at the complexity of the system indicated here, these systems cannot be easily designed or constructed by the normal neuroscience laboratory, like the life science laboratory. It really requires the power of industry to come in with engineering teams and mechanical and electrical engineers to be able to design and implement these things and provide the technology and resources to a large army of neuroscience labs throughout the U.S. That industry component is absolutely critical and that's what this photonic industry group is trying to facilitate.

Here's an example that once you have the map, you want to be measure what's going on within the circuit dynamically and this is a picture of the circuit dynamics of a live mouse going about behaving. On the right is the actual flashing neurons and once again, you can genetically engineer these neurons so now they're expressing a protein that is fluorescent where calcium is released and when the neuron fires, it releases a burst of calcium and you can see the functioning processes of the circuit in real-time.

To me, this movie and movies like it are comparable to when I first saw the surface of Mars when NASA, just blew me away. I never thought in my lifetime, that we could measure the information processing going on within a living brain. Now, this is becoming a routine part of neuroscience exploration in the brain project.

This requires very sophisticated photonics technology as indicated here. These are miniature, high resolution infraction microscopes as indicated on the right and this is a device that was recently developed by a company called inscopix started in Silicon Valley and a spin off from Stanford.

Again, this is technology that cannot be developed in the standard research laboratory and inscopix has now enabled about 100 laboratories throughout the country to be able to do this research of mapping the dynamics of the brain. Then once you map it, you want to be able to probe it, injecting signals and blocking signals and once again, we use this technique optogenetics, molecular manipulation of the neurons in the cells express proteins which in this case, block or excite neurons. On the left here, the mouse running around the circle has neurons that are activated or are expressing a protein which allows light when the light is turned on, the right side of the motor control of the mouse is activated and you can run that one again. And it begins to run in a circle as long as the light is on and when the light is off, the mouse stops.

On the right hand side we have a movie of a mouse where the areas of the brain that control fear and anxiety are now under light control and this is mouse is rather timid as soon as the light comes on, it happens just about now the mouse loses its fear and anxiety, exploring the maze without no hesitations. We're now beginning to understand how we can probe and control the different positions of the brain using these techniques.

Once against, this requires technology. These wearable microscopes and technology that's really beyond the range of most neuroscience laboratories and the control, the input from U.S. industry is going to be critical to allow this to be expanded, this technology be to employed and expanded around the research labs around the country.

So now we have begun to explore how we can map and measure the dynamics of the brain's circuitry, how can we use this knowledge? This is a wonderful example of the frontiers of employing this technology. This is some technology that's been developed at Stanford by using retinal implants to restore vision in patients. These are photo arrays that have been implanted underneath the retina that are then excited by a camera that captures an image and that image is written using an infrared laser on the photo diode array which is indicated right here.

This has on its back micro structure that is designed to allow the neurons to actually penetrate and make electrical contacts with the photodetecters so once again, we have very sophisticated technology that's not available to the average neuroscience laboratory that is going to require the input from US industry. So the essential photonic technologies that are necessary for these frontiers in neuroscience to be fully explored are indicated here. These technologies are well represented by the competencies of the companies we have assembled together.

So what are we doing? We're meeting on a quarterly basis as the scientific conferences are organized by the scientific societies behind the national Photonics and we are working with the academic research community national education and the industry to generate road maps as well as to promote collaboration activity involving both precompetitive research as well as individual cooperative research development agreements between companies and leading research laboratories.

We'll also be trying to recommend specific funding opportunities to support these collaborative activities for the funding agencies.

Something we'll be putting in place over this next year is mechanisms for technology transfer centered around training programs that will allow principle investigators, postdocs and graduate students to be part of the product development teams and industry as developing these new technologies.

Tech transfer is a contact sport, and requires people to work in close proximity and we feel the intern program that would support both principle investigator and post doc graduate students to be a tremendous educational opportunity as well as a key way to transfer tech to the private sector. So with that I'll close.

Eric Lander>> Well let me thank the panel, I think just for the last topic that we have discussed. You have really opened this up to a whole range of extraordinary things that are going on in neurosciences right now and it's clear that as the fundamental developments in basic biology, emerges from basic curiosity driven research and under lining everything that we have been talking about has been amazing in academic science. It's really clear that the partnership with industry is going to be very important to fulfilling the promise of all of that and there's this great, I think it's true in so much of all American science interplay between the public and the private here in developing insights into neural circuitry leading to the idea of neurceuoticals that can control it. It's clear that the neurindustry has critical roles and getting the technologies out and really taking advantage of finding control of the neural systems, it's just a wonderful thing to see how much has been happening under this brain initiative.

So you have done your job well of leaving us that 15 minutes left of discussion and our pattern at PCAST is for members to raise their flags and I don't see any flags up but I would not be surprised to see that shortly, minds are blown about what is going on here. I think they're all sitting here looking for somebody to push the button and reduce their fear or something like that.

You know, for the PCAST members, if it turns out you actually at least currently as configured need to have a genetic protein expressed in your neurons so they can’t currently do that for you - - so but for the meanwhile, Jim Gates and Bill Press have overcome their fear and Jim, all yours.

Jim Gates>> Thank you, and first of all, thanks to the panel for that great briefing and Eric is quite right. I have never seen PCAST respond with a lack of flags so you're the first set of briefers who have shut this group down. But only briefly indeed. In fact, I was during your presentation and there was a program called the bionic man back in the 80s. And Boy, doesn't this begin to look like it? More seriously, though, as we have looked as those stunning possibilities that are out there, is it too early to start talking about two sets of issues? One we saw playing out for example, in the genome, and one was around ethics surrounding the developing business sides and the other is to start thinking about other - - well, certainly this is an initiative that has been enabled by this forward thinking view that the USG has taken in this realm. Do you see things on the policy front that a group like this would be thinking about to get this on the next stage. These are my two questions.

Thomas Baer<<I think they are very important questions. I think it's absolutely critical that the U.S. take the lead in this area because for economic reasons and competitive reasons and the great frontier of science but because of the value with which this country holds privacy and individual freedom.

I think it leads the world in those concerns and I think this research raises those fundamental ethical questions at a level that no other research I have ever seen does. So I think it's extremely important that we put in place the structure to deal with those issues because we're going to be developing technology that is literally mind blowing and I think the US is the appropriate lead country and culture for guiding that research.

Robert Wells>> Can I respond to that too? I completely agree. I think we did a terrific job as a country during the human genome project. If you recall, there was a set aside, a certain percentage up front to deal with the issues and there's a host of fascinating LC issues, even ethical, legal, social implications for those who know it. And I happened to be at the time, in the life science space and worked on the genetic privacy issue a lot and the non-discrimination issue. I think that one of the really positive things coming out of this that we're doing in the brain right now is to start to destigmatize a lot of the conditions that people have, neurocognitive and neurodegenerative disorder. We really need to do that.

Sometimes when you talk about the ethical concerns, it comes across as a negative thing like something to be afraid of. It's true in any situation like this, there's a lot of things we need to take into account and think proactively about how we deal with this and some of the privacy issues but I think we also have an enormous positive opportunity here to start to destigmatize and to take out of the shadows, people who have been afflicted with these conditions and that's part of the ethical mandate as well, the legal issues are fascinating here.

If you start talking about the world of intellectual property and how it's challenged by these new discoveries and how we might think about innovative, upstream ways to work together and bring more precompetitive IP together and more ways to put the tools of discovery together so people can use them in a way that has maximal societal benefit, I think that's a powerful discussion to have in this space. I just under line what Thomas said. I think getting involved in the discussion early benefits us to do it. I was in Europe earlier this week at a meeting and one of the concerns there when you start talking about privacy is that Europe has some very strong privacy guidelines which in many ways can actually impede some of the research that we like to do and the ways we would like to work.

Part of that reason is because we have a fair societal concern about individual privacy so I think we need to have a discussion with that earlier and not later. We benefited from that in the genome era, I think this served us really well. NIH gets a lot of compliments in my book for sheparding that and we should do the same.

Kriss Famm>> I agree with that. On the ethics side, I do think it's time to do it now. And talk about the neural data in particular, where we put neural recordings, in health and disease, how we share that. That is a good question I think we need to arrive at as a society, and that time is now. On the comment about the bionic man I think this is one we often hear and what we need to be, at least careful with so it doesn't backfire, right? To understand the electrical impulses is a chance to be a major class of medicines to help severe conditions- - just like the pacemakers are not seen as something like, half machine and a half man. We need to find the path to arriving at new modulation in a similar way. If we help arthritic patients to walk when you look at Parkinson's patients who all of a sudden we were able to get rid of that tremor - - it is fantastic and we need to place it properly there. Living in Europe and seeing how GM crops backfired in Europe, I have to say, it is something that I sometimes lose sleep over, we need to get this one on the right trajectory.

Jim Gates>> Thank you very much. I just want to make sure that no one can hack into my son's brain.

Robert Wells>> I have one more comment to that just very quickly. The second part of the question you asked and I don't want to let it go is the policy frame work issues that PCAST can think about. We've been putting some thought into that. I'll put on the table, a way to sort of organize it. So we have the five Cs, connectivity, commonality, convergence, collaboration, and communities and just briefly, connectivity is talking about big data. How we bring data together and how we harness it, what the policies need to be so the researchers have maximum access to the data. Making these data sets talk to one another because it's absolutely vital to do.

Commonality, standards, the whole issue of standards and I'm sure colleagues from the national institute of standards and technology can be real philosophic about it but there are so many technologies and they need to bring some standardization to that.

Convergence, Eric, you're part of an organization that preaches the Gospel of it. It's really the biology that meets the electronic circuitry that meets the physics, that's critical.

New models of collaboration and how we can enhance those, I think that's critical, and last, the sense of communities. The patients and the caregivers in the neurospace, the caregivers for patients as well so all of these have policy issues around them. We recognize that I have been trying to frame work and think about it to really answer your question, the policy things we have to pursue in parallel with the science because that's the scaffolding around what is all going to succeed.

Eric Lander>> Great. That is really an important set of questions especially from neural effects on the periphery to the neural effects that are primarily essential. It's very important to get this right. Thanks guys!

William Press>> Thanks to all of the speakers. I'm especially interested in this interface between the science discovery and the instrumentation builders because I've seen in several different fields that I have worked, those kinds of relationships develop so for example, astronomers always had a close connection to the people who build the tools that go on the telescope, and physics labs. I remember a time when you could walk into a physics lab and it didn't look like a laser lab. Now, all physics labs look like what Thomas showed and possibly complex until somebody explains to you, no, they're really understandable subsystems here.

It seems to me we're at a time where biology, bio sciences generally is acquiring a much closer connection to the physical sciences to the instrument builders to laser technology to many new imaging technologies, and I wonder if any of you have thought about how is that going to affect the field? Are we going to be training biologists to know more about lasers? Is it going to be strictly a research lab, buying things from industry split, or what is the right way to build the right eco system here between the instrumentists and the discoverers?

Thomas Baer>> Being involved in educating students in doing a lot of career counseling. My view is a multi- disciplinary team is best composed of multi-disciplinarians where each person has expertise in a wide range of fields and that's the most productive team. We found that in the private sector and managing instrumentation and development groups, commercial product development groups, so my view is we are leading towards multi- disciplinary trainings that need to break down the ivory tower walls and provide the background and training to scientists in areas of technology development. Just as important, taking the engineers and the applied physics people that I have worked with and training them in life science. It's not just the details of the technology but also how the science is done, getting back to ethical questions, the animal research and what you can and cannot do as a scientist which are fairly wide open in the physics regime but very limited in the life science. Learning how to work within the constraints, design and obtain valid data which can progress the field. I think this is a wonderful opportunity for the educational system to rise to what I think is a growing challenge that you very well explained.

Kriss Famm>> Can I add on the note of multi-disciplinarity there, I think it's important to remember that what industry wants, the new talent to build this sort of product, we need experts in the different domains, we need someone who has a deep spike of expertise in one area and then this capability to interface across right? So we need to get the balance right and I think there's much more of a collaboration model. Between the academics and industry, we need to find a way where we can link up the various disciplines here and link up instrument experts with biology experts with neuroscientists.

That still requires a culture change to get them forward. We have tried to coordinate a network that has much further to go, I think.

I think the agreement, in working between - - indeed between the different countries here.

Robert Wells>> I would agree with all of that and I think if you go to the research labs I was mentioning a minute ago and you look at the younger scientists who are coming in, the multi- discipline is something they have and want to have more of. In the neuro space, one comment I have, I have learned this and it has surprised me is that this particular space is still comparably fragmented and siloed. So to the extent we can use that multi disciplinarity and generational change and the emphasis of programs like the brain initiative to try and bring those silos and communities closer together, I think that will benefit us all but to the overall question, the answer is yes, the more multi- discipline, the better.

Eric Lander>> I think our last question goes to Jo. We have two questions, Jo and then Maxine.

Maxine Savitz>> I have a follow up - - also a comment on tech transfer, having come from industry, IP is always an issue. Have you set up or have some guidelines for how you're going to do the IP as you have this industry who is working. I do like the idea and we ran a signal, a lot of programs where we had interns in industry, and that tech transfer, but we still have the IP issues to deal with at Universities. So have you frameworked it and what other technologies do you have in mind?

Thomas Baer>> There has not been a formal policy set but I have some great role models. Stanford University has a tremendous office of technology licensing and a very successful track record of working with companies to transfer technologies out of Stanford and also, intern programs. I think there are precedents for successful programs that recognize the intellectual property rights of companies that are collaborating with academic researchers but that is indeed, something that we need to address in particular by this industry group to decide what the boundary conditions are.

I'm highly optimistic we can deal with that and I think it does vary depending on the agreements whether it's a cooperative research and development agreement that is narrowly focused or a collaboration which is more precompetitive but I think there's some very good example of how we can make it work.

Jo Handelsman>> A subject of interdisciplinarity, the connection to neural biology and electrical engineering is pretty obvious, were dealing with electrical circuits. What seems to be left off very often is micro biology and often, within biology, we tend to leave out collaboration and tend to look outside at the physical sciences and technology for our collaboration. But like I said, most of what they talked about has some microbial contribution. We have known since the 30s that rheumatoid arthritis has microbial component and in some cases are completely treatable with tetrocyclin. Every other disease, like diabetes and depression seem to be responsive to at least in part to microbial treatments and we know that half the serotonin receptors in the body, or in the GI tract are in direct contact with microbes and microbes produce serotonin mimics-- so is that part of the equation of how you're dealing with the brain initiative, the so called second brain, is that part of your equation?

Kriss Famm>> Well, one clarification, we not saying that bioelectronic medicine is going to be the only therapeutic intervention, of course antibiotics and molecular medicines in general are, and will remain absolutely critical for us as a company and for the field of medicine. Understanding of micro biology and if I could expand it to, cell biology and organ biology in general is absolutely critical here. Whole organ physiology has been an ignored science when we're down in the molecular world for a while and that needs to come together now. Specifically addressing the point about microbial and the link between this and the brain. Yes, it is there that interesting aspect in everything from developing from the more obvious inflammatory bowel disease, or CNS conditions that are coming up now. We are looking at, from whether we can intervene there between the nerves that sits between the gut and the brain right? But actually, this might be the microbes in our GI tract - - again, we have different fields of biology there.

Jo Handelsman>> But if your targets are actually gut microbes. It might be different nerves or circuitry that's playing a role.

Kriss Famm>> And here, the nervous system is incredibly complex as well.

Eric Lander>> I want to very much thank the panel. It's very great complimentary amongst you, You have just opened it up to a whole range on what is going on in the brain initiative and shedding light on this whole corporate laboratories. I'm going to thank you on behalf of PCAST and turn it on to the brain issue.

So we are now scheduled to take a break of ten minutes and then we'll resume.

Ebola: Brief Report on PCAST Exploration

Eric Lander>> Great, I would like to just welcome everybody back from the break. We're going to continue with the next portion of this morning's PCAST session. I just want to give an extremely brief update about a meeting that PCAST had in between our last formal bimonthly meeting of the Council and today's meeting of the Council, and that was a meeting with the President on October 23rd which had not been scheduled in advance. The subject was Ebola, and in the course of the work that the President was doing of ensuring that the federal government was doing everything that it could to address the issues surrounding Ebola, he also wanted to meet with his PCAST and get our take on what the federal government was doing, could be doing, any ideas that had impacts both in the immediate term or the medium term, as well as in the long term with regards to responding to threats about that.

So in about four days notice, the PCAST assembled in Washington, in fact a substantial majority of PCAST members were able to remarkably rearrange their schedules and were able to come, and we met with the President on the afternoon of October 23rd and I just wanted to report that in public session.

I'll just briefly mention a little bit about what the topic of the discussion was. The federal government has been swinging into action in, I'll just say personally, a remarkable way for a disease that is killing thousands of people in Africa, but is not currently a threat in the United States by comparison.

You could say many countries should be taking responsibility for ensuring that we're managing that epidemic in Africa and providing the help and the assistance and the medical leadership, and I think it's really clear from what we have learned and from what I think the American people know, is that the United States has really taken the leadership role in the world in ensuring an adequate response. We have been deeply impressed with what is going on.

In the course of a relatively short period of time, the United States government has really worked to ensure the ramp up of production of therapeutics and vaccines. It's not an easy thing to try to accelerate dramatically the production of vaccines, for instance.

We have some experience of that on PCAST because the first report we did is on the H1N1 flu, and our experience as a nation with the H1N1 flu happily did not turn out to be a seriously lethal pandemic flu but that could have happened. Our experience was that the vaccines that came along, came much slower than we would have liked. PCAST wrote a second report that addressed how can we ensure that the next time, that flu vaccines would move faster.

Lots of things have been done in the interim with regard to pandemic flu vaccines that increased the preparedness of the nation, and it's really heartening to see that some of those are having an effect on the production of the Ebola vaccine, the ability to speed up sterility assays, that is to measure whether or not the vaccine is contaminated in some way, the ability to rapidly get fill and finish capacity.

Everything from the science to the manufacturing has gotten sped up because of the national learnings from the H1N1 flu situation. That doesn't completely solve these problems, but it's good to see in each particular emergency situation, we're not just addressing the emergency situation, but we're looking over the horizon to address the issues that may arise in the future and get better every time. So it's good to see that. At the same time, there's unique issues, many unique issues posed by Ebola with regard to, therapeutics and vaccines and it's great to see that U.S. agencies from BARDA and HHS and CDC and FDA, have stepped up in partnership and have managed to clear regulatory barriers. It's like, oh my goodness, how are we going to get this all done, and it turns out, if there's a need, we can meet that very quickly, and we are seeing that.

So what PCAST has been asked to do is look at the situation and make comments like, are there places we can see, are there ways we can contribute to and add to the already impressive ongoing efforts. I focused particularly here on thinking about Africa because Africa is the major place there's an epidemic and to the extent there's any cases coming to the United States, they're coming from Africa here and if they're not dealt in Africa in the long run, we will continue to have cases appearing here from time to time.

And there has been tremendous focus, we have learned, on ensuring the protection of the United States, and ensuring we have the ability to do rapid diagnostics, and tell whether someone has Ebola quickly, and there has been great progress in the past couple of weeks in developing rapid assays that are already in testing using things like (inaudible), something of the kind of things that a pregnancy assay involves. So we can make those discriminations, which is important when we enter flu season because any virus initially might have similar symptoms and being able to differentially discriminate between the almost always it is influenza, and very rarely for someone who has the right contacts, it might be Ebola. It's helpful to have those tools, and good it see it happening. So it's been a very impressive process, both in the setting up procedures to ensure the protection of the United States, and accelerating the efforts to develop therapeutics and vaccines to cut off the epidemic at its source, as well as great efforts with regard to public health because one of the great ways to end an epidemic is public health measures, as well, decreasing contacts, contract tracing, and CDC has been working hard on that. So I think PCAST met with the President, offered some observations about mostly very complimentary observations about what is going on. Some thoughts about additional things to look out for. What to do if plan A doesn't work, what does plan B look like, plan C look like in regard to vaccines and making sure there's enough things cued up in the pipeline behind it.

And I think particularly thinking about what learning should come with this. How do we use this to go even faster because we will, we know from the past decade, we see the emergence of new viruses with some regularity. There's often flu viruses, there's Ebola, and other viruses, lots of fever, for example, in the same area of West Africa. A similar hemorrhagic fever or virus belonging to the filovirus family. We need a capacity as a world to be able to deal with this in a rational, calm, scientific based process that gives us the tools we need, and I think my summary of the PCAST interaction so far is pretty impressive to see the learnings that have happened, and recognition that every single event has to get us better and better.

The safety of the American people, so far seems well protected in this, but we have to remain completely vigilant both at home and abroad and for the future. So that's my brief summary of our interactions. We'll continue to do whatever the President asks in this area. I would ask has John have something to add because he's been deeply involved in that in his role in the White House and I will turn over to him.

John Holdren>> Thanks Eric. That was, I think, an excellent summary on our interaction with the President on this and as you said, we will continue to be responsive to the President's interest in having our advice on that topic. But you're also correct, there is a very wide ranging and deep running set of activities across all of the relevant agencies in the United States Government dealing with Ebola both in Africa and to the extent it comes here.

Technology, Innovation and DARPA

John Holdren>>It is now my pleasure to introduce Dr. Arati Prabhakar, who is the Director of the Defense Advanced Research Projects Agency, otherwise known as DARPA. Her biographical material is available to PCAST members in their briefing books but for the benefit of our wider audience, I would note Dr. Prabhakar has had an amazing career. She was the Director of the National Institute of Standards and Technology in the Clinton administration. She then went to Silicon Valley and had an amazing career as a Senior Official at Raychem Interval Research US Venture Partners. She got her Ph.D. in applied physics at Cal Tech, while also collecting a masters degree in electrical engineering, which makes her both a scientist and an engineer, and very appropriate given DARPA's mission. She also had an earlier stint at DARPA in 1986, she started at DARPA and became the Founding Director of DARPA's Micro Electronics Technology Office. The other thing I found fascinating in her bio is she started her career as a congressional fellow at the late lamented Office of Technology and Assessment where Rosina Birbaum was also employed at the time, our fellow PCAST member. So Arati it's really a pleasure to welcome you to this PCAST meeting, we're eager to hear from you about breakthrough technologies for national security.

Arati Prabhakar>> Okay, now I'm on. Thank you John! Thanks to PCAST for the chance to be here with you all today. I'll just add as a footnote that when I first arrived at OTA, the woman who sat next in the office next to mine was Marjory Blumenthal and you're all are very lucky to have her now.

It's just great to have this chance to talk to you now about DARPA. What I thought I would do is give you a little bit of background and context for the work that we're doing, share with you six brief examples of projects across our portfolio, and then try to use most of this time for conversations.

I'll try to keep it brief and zip through the materials I have in the interest of time to get to the discussion. Many of you know that our story at DARPA began the year before we were formed in 1957 when the Soviets launch Sputnik. The U.S. response to that surprise included many things that I suspect later made the Soviets regret that they launched Sputnik. One of the things we did in 1958 was to establish the original ARPA Agency which became - we sometimes have a D and sometimes don't - but it's the same agency, it's the Defense Advanced Research Projects Agency, and if you think about the late 50s, that was a time in the post-World War II era, we had started building what is today, the federal R & D system we have today. In the Defense Department, we had R & D activities in the Army, Navy, and Air Force, but Sputnik said we needed a specific entity, a specific place, whose day job is to think outside and beyond the known issues and the known opportunities that we were dealing with already. And that was what DARPA, that was the reason that DARPA was created. My predecessors quickly realized that the best way to prevent technological surprise was to create a few surprises of our own, and that's been the history of the agency for now for nearly six decades. My partners and colleagues in the Defense Department know us as the place where the technologies for stealth and precision guidance and navigation and advanced battle networks, where those technologies originated and were demonstrated, the technologies that have changed how we fight. And my Silicon Valley life, I found that the technology community knows us as the place that helped form the discipline and material science that laid a lot of the ground work for what is the information, technology revolution that's in full bore today ,and that duality of military technologies but and also the core enabling technologies that we invest in because of their national security promise, but which we know often historically spill over, and can form the foundation for products and companies and often even industries because of private sector investment. That duality is very much part of our history, and I think you will see and the work we're doing today, the potential for that in the future.

Now, we're a place that's very proud of our history, but I want to underscore that nothing I have mentioned happened single handedly because of DARPA. We are 200 government employees in an office building in Arlington, Virginia. We are part of a vast and complex and intricate technology ecosystem in DoD, in the Defense Department and we're part of the larger national R & D ecosystem that you all represent from all of the different perspectives that you have.

The only way that we can get our job done is in fact, to be able to tap that incredible, vibrant robust ecosystem that we are part of. Within those communities, though, DARPA has one particular job and that is to make the pivotal early investments that change what is possible to make the big strides forward in capabilities. That's where we live and breathe.

So that mission of breakthrough technologies for national security has not changed in all of these decades at DARPA, but of course, the world in which we operate has changed and changed and changed. So today it's important for us to be clear about the context that shapes the investments that we're making for the next generation.

Let me mention to you sort of the major parameters that shape that context. In many ways, our job at DARPA is informed by the challenges of national security and then inspired by what is possible in terms of technology. So let me try to give you a little bit of sense on both sides in the context that we're living in today.

The national security world that we live in today is one that is characterized, I would say, by its diversity and by the pace at which it is changing. My first tour at DARPA started in 1986 when arrived, we were in the Cold War and very sure it was going to last forever and we were completely wrong about that fortunately but that was a time when one monolithic adversary focused our attention and drove all of the thinking about how we made our investments. I returned to DARPA in a period when we were winding down from two ground wars, a focus on counter terrorism and counterinsurgency, and what I quickly realized as I came back in the national security environment, is that for today and the decades we see out ahead, in fact, our nation is going to have to deal with the questions of national security challenges from nation states, the questions about what is Russia exactly trying to do in Ukraine? Where will China's growth and its ambitions and its changing role in the world, where will that take it? What is Iran going to do? What is Korea going to do? Those are still major questions. At the same time, the chronic national security threat and the challenge we deal with literally everyday is about the nexus of terrorism and criminal activity, cross border criminal activity, and then often linkages among those communities back to nation states. It's the shape shifting diffuse networked threat. A set of linkages that have existed throughout history but now are empowered by global technology, so that is the breadth of the national security challenge that we have to keep in mind, and then on the technology side, in fact, the world is also quite different because much of our R & D ecosystem in the U.S. in the national security world in particular, was built in a time when we could make U.S. technology investments in confidence so we would have a 20 to 40- year period of proprietary advantage, and course that's not at all the world we live in today.

This year, we'll have 7 billion subscriptions to mobile phone services in a world of 7 billion human beings, a mere 3 billion people have access to the internet. Their ability to access cyber space, their ability from a few click strokes to get access to amazingly powerful microelectronic components, and those are the things that have been incredibly good for the human race and for elevating living standards around the world, but they also pose a new kind of national security challenge for those of us who live in our world.

So that global technology context is a very different and also, critical part of our context at DARPA. So that's the backdrop, let me try to give you a sense of some of the things that we're doing in the agency today, and just to put it in sort of three major categories. I'll give you examples in each of these. A good portion, probably about half of our investment at DARPA today is in the business of rethinking complex military systems. In one domain after another, what we see is that our very complex, very very powerful, very capable military systems are reaching a point of diminishing returns. We have saturated our capabilities in many regards, and I will give you a couple of examples, but the theme you'll hear is the need to get on to a new curve, typically characterized by new architectures for thinking about how we're going to generate the military effects that we need to be able to do for the next generation.

Approaches that break a methodology that is about big monolithic, costly, slow, hard to upgrade platforms. That's really how we do business today. It's just not going to cut it for the next generation. One major theme, and I will give you some examples in a minute.

In terms of the information realm, when I was at DARPA 20 years ago and you talked to people in the military, they sort of knew something might be happening with computing and communications but it didn't seem central to their business of national security or military capabilities. Today, when I talk to senior leaders, a couple of days ago, I had the opportunity to sit down with the General Odierno who is Chief of Staff of Army and he started by talking about, well, when I went into Iraq, I had no data and by the time I left, I had too much data, and I was drowning in it and information is now integrally part of the national security enterprise at all levels.

I think we are in the middle of a long and very, very productive time in the information revolution. Today, the challenges we're facing have a different character than the ones I saw a few decades ago at DARPA. Today the challenges are about dealing with information at massive scale and I'll give you a couple of examples of things we're doing there. Finally and always, one of our jobs at DARPA is to constantly be surveying the research horizons, and to be looking for the places in basic research where the pot is really bubbling. Much of that research is simply going to be wonderful science! What we're looking for is the places where we see the seeds of technological surprise, and that happens in a number of areas. There's work that we're doing in the advances in cold atom physics, and new areas of chemistry, and new areas of math and algorithmic approaches, but one area I really want to highlight today is the area where biology is intersecting with the physical sciences and engineering and with information technology, an area in which DARPA has been working at a modest level over about 20 years now.

But where we recently formed a new office, a biological technologies office, to really seize this opportunity, to start shaping biology, not just as a science, a discipline of science, but really, as a core technology and in fact, you just have been talking, Eric, your comments a minute ago, the work that was being discussed about the brain initiative are terrific examples. I'll share with you the work we're doing in those areas as well.

Let me start with complex military systems. Let me start by giving you one example of how we're trying to rethink the architectures for these complex systems. On the left is a depiction on how we currently do one of the things that needs to be done in a complex military operation, an air operation in this case. That little rectangle on the top left is an adversary radar system. The aircraft that you see on the left hand side, its job is to jam that radar so that the adversary can't see us coming in to do whatever it is we need to do, and the way we do that job today is about $100 million system. It's a very expensive aircraft with an expensive electronic warfare suite on it, essentially sending out a very powerful radio signal that jams that receiver. Now, to deliver that much energy on the ground where that adversary radar is, requires this massive beam. By the time that beam comes to ground, it covers an area about the size of the beltway around Washington DC, carpet jamming everything that is in the way, including us. We try to operate in that arena. We can only go after one radar at a time and when the adversary starts to figure out where that jamming signal is coming from, it's not hard to find because it's a big monolithic source.

Over time, the adversary is going to get better. That's what happens in this world. If over time their ability to push us out farther increases, then what we have to do is go through, typically a 10 or 15- year block upgrade cycle, back to the drawing board, a huge amount of time and cost to do an upgrade.

The question we're asking at DARPA today is can we break that model? If you look inside that aircraft, inside of that jammer, what you'll find over many generations is advances in micro electronics capability that are really pretty amazing, and are power amplifiers and better use of digital of silicon technology, more powerful antennas. What we have done with all those advances in the past is just cram more and more capability onto this one monolithic platform. Today, we're saying let's see how can we use those advances in a radically new architecture, and one of our projects today is to try to demonstrate what you see on the right where that jamming, instead of coming from one monolithic source, is actually coming from a collection of cooperating micro jammers, because the energy they need to deliver on target is actually squared as the electromagnetic energy is aligned with high precision and that's one of the hard challenges, but because of the way that the energy is being delivered, this actually goes as one over n squared.

So each of the six small transmitters only needs to be 1/36th the size of the thing on the left hand side, an amazing scale opportunity there. They're able to do precision jamming. They can go after multiple types of different radars. When the adversary tries to see where that signal is coming from, it's not coming from one place, it is coming from many places. It's going to be much harder to find, should they take one of our small UAVs out, we still have the ability to deliver quite a lot of capability on target. And when the adversary increases standoff, now instead of using six units, we use nine and we can do instantaneously, not in 15 years. Enormous advantages. If you think the technology is hard here, and it is because none of this is trivial, this is the kind of thing that's going to give our partners in the Air Force and in the Navy, tremendous headaches because it completely changes how they are going to operate and it speaks to what kinds of barriers these technologies face in the future.

But when you see how much more capable this future picture is, and the fact that this will allow us to drop costs and actually build systems in volume instead of just building Powerpoints for the future, Mm hope is it will be compelling enough that we can actually start moving to these new kinds of architectures. That is one example. . Many, many other examples in terms of distributed battle management, distributed communications, distributed radar systems, distributed position navigation in timing rather than relying on GPS.

In a different domain in space, a very similar story. If you think about what is happening on orbit over the next few decades, space is becoming nimble, agile, real time through commercial activity, through the activities of other nation states as they enter the space domain, not in the 50s and 60s, but with the technologies of today. Meanwhile, national security space has gotten slower and slower, and more and more costly. Today, when we want to put up a major new national security capability on orbit, it typically it is a multibillion dollar proposition in development, multibillion dollars to get that then launched, and even worse than the cost is the amount of time. If today, we know we want to get something on orbit, it's typically a couple of years before we can get it on orbit ,and when we go, when we launch, we only have a very small number of fixed launch sites to access space from. That's just not going to cut it in the real time environment we're in, and the work we're doing at DARPA is to demonstrate some radical changes in many elements of it.

I will just highlight the launch piece in the upper right here. The revolution in micro electronics has allowed us to build very powerful small satellites, and we are seeing that in the commercial, in the civilian and the defense sectors, but if we don't break the launch part of that, then we're not going to get the flexibility and the real time capabilities that we need. One of our programs in this area, a couple of programs in this area, aim to change that dramatically. One of those, our LASA program, is essentially a technology that would allow us to, out from an F15, from any airfield in the world, be able to put 100- pound satellite into a lower Earth orbit for a million dollars. That's ground breaking! Even more ground breaking is the notion that you could do that on 24 call up, and that's, I think, a great example of the kind of disruption this environment really calls for.

Let me shift gears and talk a little bit about the information domain. One of the problems that we deal with in information technology today is that all of us in our work lives and personal lives but also in the national security sector, we are so critically dependent on information and our information systems but these are not high trust environments today, and the challenges of cyber security are something we're grappling with. Many people today, whether in the private or the public sector the way we deal with cybersecurity today is patch and pray. We find vulnerabilities, we manually address them, and the only way we know how to scale our cybersecurity capabilities today is to hire as many people as fast as we can and have them plug holes as fast as they can.

That's a smart strategy today because we don't have an alternative. Our job at DARPA is to try to create an alternative for the future. Our core objective here is to come up with cybersecurity approaches that fundamentally get ahead of the scale in which information is exploding, and with it, the vulnerabilities that are also exploding.

One technology program in our cybersecurity portfolio is the cyber grand challenge. This program, if folks know about DEFCON, major hacker conference that happens once a year in Las Vegas. At DEFCON is a well-known challenge, capture the flag where teams of hackers compete to try to keep their systems up and to avert attacks and attack each other, and to win by controlling their systems in this fierce competition in an isolated cyber environment.

It's a perfect example of what we're trying to do manually today but it is also a great competition that allows us to see the best in human reasoning about the cyber environment and cybersecurity.

The cyber grand challenge aims to us to get on a path to be able to do that kind of cyber security in an automated fashion, and our analog here was when we started building a league of their own for computers to play chess.

Back when we first started, computers were really bad at playing chess and humans always whooped them, but when they got a league of their own and they started competing against each other, they pretty good to the point they could beat humans, and that's now what routinely happens. Cyber grand challenge is going to create a capture the flag environment specifically for automated competitors. We have thrown this open to the whole world. We have gotten about 80 people signed up, and there's still more to come from every part of the world. We’ve gotten hackers, amazing academics, people from companies, and we're going to give them a chance to play capture the flag and start building our automated systems which at least have now, the hope once we start down the path, of getting faster than, you know, the typing speed of the best fastest human hackers to deal with the automated scaling threats that we're facing.

That's one problem in this information domain is trust. The other issue has to do with how we get value out of this deluge of bits that we all live in, and again, a number of programs that are going on at DARPA, I want to just share with you one new program called MEMEX. This was a program that is setting out to create a different approach to doing a different kind of web search today, very different than what happens with commercial search engines. The program manager here, Kris White, when we started MEMEX, he did a little ceiling project to see if there was really a there/ there, so he started working with some of our colleagues in the law enforcement community who were working on human trafficking. Well, what he found was the way they explore the online space of sex services ads was pretty much the way that you and I search on the web, the sort of single threaded walk through this vast, seemingly infinite space. It's a very difficult way to try to piece together a story on how networks might be hidden in that online space.

Our team built a tool that allows us to look across the set of those public ads and again, privacy is always an issue when we're talking about data. Here, we're talking about the most public information there is. It's advertising information. The team put together the capability to look for signals in those web sites, phone numbers as an example, and you can see the cluster map on the left where some phone numbers seem to show up over and over again. They pull together a picture of all of those clusters looking to see where the phone numbers were that were most frequently popping up in one ad after another.

They took from that cluster map, and again, all of this is done just on public information. But we took 600 phone numbers from that analysis, threw it over the fence to our law enforcement colleagues, who then compared it to their carefully developed database that had been built after many years of arduous work. They were surprised to find from the 600 phone numbers we discovered, those numbers tied to over 400 known criminal violations, which was interesting enough, but then they found that among those phone numbers were links to 30 fund transfers and the regions around North Korea.

That tool, which was actually a very seedling project, has now become a very, very valuable tool that they are using to start being able to focus their attention on to these places where they can chase leads for potentially running down these kinds of human trafficking networks that span the world and actually, also, then tie back, you know, to our world of national security; I think a great example on how national security has linkages now into the law enforcement world. One example but I think a very interesting national security and law enforcement contrast to what is going on in the private sector.

Let me finish with two examples from the world of biology. This is a perfect follow on to Eric's comments on what is going with Ebola. The way we are going to deal with infectious disease is always going to be, first and foremost, diagnosing what is going on and tracing it, and secondly, trying to find a way to build a fire break and then provide longer lasting immunity to broader populations and the things that you talked about Eric are, I think, are exactly what we need to be doing in each of these areas. The question that we're asking at DARPA is, can we look for techniques that will allow us not just to shrink diagnostics from a lab scale to a desk to, and not just do vaccines more quickly, but can we find some fundamental advances that will allow us to completely collapse that response time and get us to the point where when the next H1N1 comes along, or the next Ebola comes along, that very, very rapidly, we can go from knowing what the new disease is to nipping it in the bud. This is a program that has been under way for a few years, but some of the work that we have been doing, we quickly realized it could be applicable in the Ebola work that's under way today that Eric was talking about.

So today we have some of our distributed diagnostics that are on the ground in West Africa instead of a machine that plugs into the wall, these are small battery operated diagnostics tools that allow for a very specific Ebola diagnosis, a step in the direction. Ultimately we want to get to the paper strip test, and I think we'll get there, but today we can do something that's already a big advance.

In terms of the transfer of antibody response and generating new vaccines, the key theme in the work we're doing today is looking for ways to develop a nucleic acid therapies and prophylaxis . Today when we want to provide protection, we either deliver a weakened vaccine to trigger our own immune system, or we transfer the antibodies from a survivor. That's some of the work that's going on with Ebola today.

Our question is, can we understand not what those complex molecules are, but can we understand the nucleic acid codes for those, and send that message, deliver that message to the human being and let the patient's cells actually generate the antibodies or the antigens to stimulate a vaccine type response.

One of the major advantages here would be the ability to provide immediate protection as opposed to the delay from vaccines, the second major advantage would be the manufacturing scale up that would allow us to deliver not just "onesie- twosie" doses as we're able to do with antibody transfer. Not just the kinds of volumes that are possible when you have to grow vaccines in living organisms, but the kinds of therapies that could actually scale to thousands, and then millions if needed of doses.

So we're trying to accelerate that work now to have an additional component in our response to Ebola, a backup to some of the other things that are going on.

Whatever happens with Ebola, to me, the critical thing is to have a platform that allows us to be ready for the next disease because the next one will come. Just to finish, I think we have talked before with this group about the work that DARPA is doing in neurotechnologies. This is part of the President's BRAIN Initiative. The work today that we're doing in revolutionizing prosthetics is wrapping up. There the key thing we were able to demonstrate was the direct neural signaling from the motor cortex being used in real time to control a prosthetic limb. That kind of closed loop real time control is a major breakthrough, and something that we are able to do with our first few human volunteers in clinical trials.

The work we're doing in memory recovery is a new program called Restoring Active Memory. This work moves not just from the motor cortex, but is now starting to look at multiple regions of the brain, and the problem we're starting with here is the question of trying to restore task memory, a particular kind of memory impairment that is common in PTSD and in traumatic brain injury, but again, I think a much more complex job than the kinds of things we did in the revolutionizing prosthetics program.

The Sub Nets program continues that trajectory by looking for the kinds of information from across multiple regions of the brain that we hope will start giving us insight into neuropsychiatric disease. And I think across that work you see a theme that's a natural starting point for us has been the restoration of function as we think about the challenges that our wounded warriors face. As we're doing this work, we're opening up very intriguing doors into possible futures, and I think very much to the comments Jim that you got going about, in the last discussion about brain function, this is probably a very good time to talk a little bit about the ethical questions that arise and a lot of the good points that were made are very much what we have in mind at DARPA. I want to say that when you start talking about what the human brain is going to be capable of, that is a very natural place to ask these kinds of questions on how society will use these technologies. But in fact, I find that those questions come up over and over again in our work at DARPA, whether it is big data and privacy issues, whether it is the safety and security implications of advance synthetic biology.

I think it's part and parcel of our mission to focus on breakthrough technologies. If we're doing our jobs, we're going to be stumbling into these new areas and dealing with these new challenges, our approach at DARPA has two parts that I'll mention. Number one, this is actually our job and I think it's important that we not shy away simply because of these challenging questions. We need to understand these questions and these technologies for our country first. That's part of it, but with it is a responsibility to raise those ethics issues and to convene that dialogue. In the case of the neurotechnologies work, we have a group of experts who we draw on to have conversations as we're shaping our programs, but perhaps, more importantly, also to talk with our performer community. I think it is important that the graduate student who is working on a DARPA contract in one of these areas knows that when they come to a program review, that we'll be talking about the societal implications of these technologies as we're investing in them.

We don't - - we're not going to come up with the answers, but I do think part of our role is to raise those issues. Let me just finish with a quick word about what it takes to do all of this. One of the things that it takes is resources. On the left, just a diagram, 135 billion is the world you all know very, very well. DARPA is about a quarter of the Defense Department science and technology investment that's been steady, reasonably steady over the last many years. The degradation in our budgets over the last few years is a reflection of the broader degradation of budgets, as DOD budgets have come down in the postwar era, strongly exacerbated by sequestration in fiscal 2013, the cumulative effects of those small cuts was about a decrease of 20 percent from our budget from '09 to '13. I was very pleased to see it stabilized in '14 and we hope to continue to get a little bit of restoration in fiscal '15 with help of Congress. We'll see how good we do on that, but DARPA, we have never inspired to be a large agency, I think it's much more important we have stability here.

The other part that's critical, and doesn't show up on a chart is continuing to have the support and confidence in the Pentagon and in the White House on both sides of the isle in Congress and I think, you know, there, I think we're in a very good place and I think that's equally important to us if we're to keep this particular kind of organization going. So I'll stop with that and let that throw it open for comments and discussion.

John Holdren>> So thank you very much for that extraordinary presentation, the first flag up is Susan Graham.

Susan Graham>> You said in the beginning of your talk, that one of the things DARPA has always done is to create disruptive technologies, and that's one of the ways that we've kept our edge. And then a little later when you were talking about the cyber grand challenge, you talked about a global competition. Now, we have always had a tension between what's ours and what is the world's, but the globalization has increased a great deal since you have first went to DARPA and the speed at which the information is communicated around the world has increased, so how do you and DARPA think about how we maintain our technological advantage?

Arati Prabhakar>> That's a very complex question that we grapple with in a couple of ways. The work at DARPA is a portfolio of individual programs, and I think it's very hard to have a blanket answer, because on one end of the portfolio, we're doing work that's classified and that's easy. We know what we're going to do with that.

On the other end of the spectrum is basic research, that if we isolate it, it will wither and die because it needs to be informed and participate and draw from this vibrant global community, and so the answer to your question is something that we try to think through for each program. It's something we talk with each of our program managers about.

One thing, DARPA does do work in other countries. It's a very small portion of our budget, and one of the things I have been urging my program managers to do, I think there's a tendency in especially in an era where there's great scrutiny and budget pressure, people tend to think of overseas travel as a luxury but I'm pushing my people - - they're very good at getting out of their offices and going out into the national technology community, that is important and we need to keep doing that, but they also need to be understanding on what is going on in the rest of the world, to be smart about it, and to draw from it.

I like the things we're doing overseas but I think that's an area where I think we still have more work to do.

Audience>> Thank you John! Thank you for that brief. You referred back to my earlier comments about ethics and as one moves into these new technological realms, the challenges keep coming, and so there's a certain tension first between proprietary or confidentiality on the one hand, and on the other hand, getting really good advice about negotiating the ethical mine fields that are out there. So I have two questions. One is, in your mind or in some of your colleague's mind, is there an architecture or programmatic structure that allows you to systemically address this question as it keeps apparently arising in different areas. That's question number one.

Question number two is, what is the role of partnership with other parts of the U.S. federal establishment in trying to address these issues?

Arati Prabhakar>> Right. The practical way that we deal with the ethical issues that come up in the societal implications issues, let me make an important distinction. Number one, the ethics, the safety, the security of the work that we actually fund, and then number two, what if it actually works? How will society grapple with what choices we want to make about how we use it? DARPA is not going to control that. I want to make sure we start the conversation for that part.

But back to the concrete part of what we do, the structures are in place so that when we do anything that involves human use or animal use, that's not that complicated. The rules and regulations are clear. The institutions know how to function, and I think it's critical and everyone in my organization knows how to deal with that. The much more subtle and complex question is, how do we start the conversation now as we're starting to see what technologies might be capable of so that others, it's almost never going to be DARPA, but others are going to be making the choices about how we use it.

We have talked a lot about how to best do this in the agency and concluded that, again, because of the diverse nature of our portfolio, I don't think there's a blanket recipe but in fact, what happens is as each new program is formulated when I or my office directors or program managers start seeing that there might be very interesting societal questions that come out of that, we put our heads together and we figure out what to do about it. Sometimes what we do is simply have a workshop, a number of opinions in order to inform ourselves as we think about our choices. Sometimes, it's putting together an expert panel that can be run alongside with us and help inform our communities in the way that I mentioned. I don't really know - - I don't want to form fit it into a standard process because I think each area is really going to raise different kinds of questions.

Your question about working with other parts of government. On the brain initiative in particular, the President's Advisory Group on Bioethics has been actually part of the brain initiative, I believe is working on some of these issues. We have had good discussions with them. You know, that's a great example of something that is much bigger than the little piece that DARPA is doing, so I think it's important for us to have those relationships.

John Holdren>> Good! Chad Mirkin.

Chad Mirkin>> That was a fantastic presentation. Good to see you. I have been a big fan of DARPA and have worked with them for quite some time, so I have learned a lot about the model. When I think of DARPA, I think they're the best at going on big ideas, disruptive technologies, and building teams, but one of the things that concerns me in terms of the recent models is that when you think about building the teams, you made a reference to graduate students coming to PI meetings and discussing what they're doing. There's a tension in the model with respect to dealing with universities and dealing with companies. The commitments, the resources available with the different groups are vastly different. So when you go from a three- year commitment or four- year commitment to a 18- month commitment, that is a huge tax on a university in terms of getting them to participate because the graduate student has a five- year Ph.D. and not an 18- month Ph.D. so I'm wondering, is DARPA missing a lot of opportunity by inadvertently pushing participation away by not addressing that particular problem.

And connected to this, if you think of the whole teaming and you take a technology development exercise, let's take Ebola, and you go down and connect the dots. You say, I need the new science that allows me to do it and the new technology and the translation, and then I have to have the buyer. What often falls short is the latter stage because there isn't a long term commitment in the business model of a company, it's to make product and sell it and make money. If you don't have a firm commitment, then you don't know there's a buyer, what happens oftentimes is the early stage is done well, but then there's a deviation, and the question is, do you get the bang for the buck that you ultimately are looking for. I'm curious on what your thoughts.

Arati Prabhakar>> I think those are two great questions. This issue, to do our work, we work with organizations that have their own objectives and universities are a great example. I think that the tension that you highlighted is something that I have seen over many, many decades at DARPA and I don't think we're ever done grappling with it. The fundamental issue is we're trying to get something done and our time frames tend to be 3 to 5 years for a program, and often there's pieces within that.

I was a graduate student once and I remember that doesn't always happen exactly on that same schedule. And I don't have a magic solution for that. I think the art of how we manage our programs needs to accommodate the fact that, especially on the basic research end of our portfolio which is where most of our university work is, I just keep asking my program managers to come back to, what is the objective? What is it you're trying to do, and often on the basic research end of that portfolio, the objective might be getting a deep new insight that tells us which direction we might want to go with something. If that's the case, you need to structure programs not to be, six- month milestones.

You know, you're just going to irritate everyone, and you are not actually going to get there, so I think - - exactly. You simply won't have the relationship you need to start with. So that's how we're trying to think about it. It doesn't always work very smoothly and I think that's a consequence of, it's the flip side of the thing that I think is great about DARPA which is we're going here and by God, we're going to get there.

Sometimes there's not very attractive consequences to that so I'm aware of it. I don't think there's a magic solution. This is something we keep trying to work on. Your second question is the perennial question which is how do you get from showing that something is possible to actually making it real. That is my hardest problem. Whether it is getting new distributed architectures into the Air Force or, whether it is getting a new therapeutic technique out into the world, especially. We're talking about Ebola in parts of the world there isn't a big market that pharmaceutical companies are going to be excited about. That is something that everyone who has done R & D shares this problem. It's something we grapple with all of the time. On the DoD side, I think, we have done a much better job at DARPA, I believe over the last couple of decades in building the DoD relationships with the military services so we know how to work with them a little bit better.

It's still hard, I would say it's better than when I was there 20 years ago. The vast number of different commercial markets and entities we really need to be able to have those kinds of relationships with, that ends up being much more retail so my people who are working infectious disease are the ones that go work with the pharmaceutical companies, and we're just at the Gates foundation because they and we share this interest in getting these technologies deployed in the world, we try to make common cause with them, but it's a completely set of conversations if it's about the next generation, some complex image architecture for a new semiconductor component.

John Holdren>> With apologies to Michael McQuade, we have exhausted the time. We are obliged to stop on time. It's noon. But Arati thank you so much for that terrific presentation!

(APPLAUSE)

We had no public comments submitted, and so we were able to use the public comment period for finishing the Q and A here mostly. Again, it's been a pleasure. I thank everybody concerned for your participation. We are adjourned.