Title	*Galaxy Zoo - The Rise and Rise of Citizen Science*
Description	Chris Lintott from the Department of Astrophysics gives a talk on the increasing significant contributions members of the public are making to scientific research through websites such as Galaxy Zoo
Presenter(s)	Chris Lintott
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Contributor Thank you for turning up on Saturday morning. It is good to see some old habits don't die out and thank you again for being punctual. I'm Prof. `[[?? 0:00:11]]`, I'm a researcher in the department of physics and a junior research fellow at Somerville. I have been deputised for the next hour or so to tell you about a project that has taken over my life in the three years that I have been in Oxford.

The project is called Galaxy Zoo and it is the world's largest scientific collaboration. It involves about a quarter of a million people distributed around the world, helping us with a fundamental problem we have; which is that we simply have too much data and too many in this case, images of galaxies, for us to analyse.

And so we think of this the first of a new breed of what we might call citizen science projects. Projects that don't just involve people like me taking to the general public. It involves scientists and `[[?? 0:01:05]]` scientists about what we are doing but people working in a real collaboration which large numbers of them is the public. So, I don't suppose I can make the lights a little more civilised, that way you can go back to sleep in quiet silence. That allows me to sleep if I do that. Hopefully that is okay you can see the slides.

What I thought I would start off by saying because we will be talking mostly about this one project, Galaxy Zoo in astronomy. Is that in some sense, astronomy amongst the sciences has always relied on the efforts of amateurs to do what we professionals can not.

One particularly famous example from early 20th century involves this man, `[[Will Hayne 0:01:50]]` who might be familiar to some of you, I am afraid it is a little before my time. I had to do some research. Will Hayne was a musical and film star. He was also a very serious amateur astronomer. You can see him with his telescope there and he discovered a spot on Saturn. A tropical disturbance in fact, on the planet atmosphere which went on to become extremely prominent back in 1930 and that sort of thing still happens today.

For example this is an image of Jupiter from earlier in the year, this is June I think, taken by an Australian amateur called Anthony Wesley. And the sharp eyed among you will have noticed that there is a black spot up at the top of the giant planet here and this is in fact an impact site. In early June something - and we don't know what it was, it could have been a comet or an asteroid - smashed into the upper atmosphere of Jupiter and destroyed itself, and what you can see there is literally soot, combinatious particles which are being thrown up into the upper atmosphere. And as soon as this was discovered every professional observatory on earth pointed its mirror at planet.

In fact this was the first target of a newly refurbished Hubble space telescope and we only knew it had happened because of the efforts of amateurs. So there have always been these, sorry, I have forgotten to, sometimes you actually need a rocket scientist.

(Laughter).

Thank you.

Very quickly that was a long - if any of you were relying on the mike, that was a long introduction and now we are now talking about amateurs looking at Jupiter, you can now go back to sleep. So the point was that for tasks involving monitoring things that might change you need somebody with dedicated telescopes and we can't afford as professional astronomers to point, say the Hubble space telescope at Jupiter everyday just in case something might happen. What we rely instead upon is a whole group of amateurs to do the monitoring for us.

If you go further back of course, the distinction between amateur and professional starts to blur. For example this man William Herschel is probably the greatest English observer of all time - the discoverer of the planet Uranus but made very little money out of his astronomy.

What he was, was a professional musician and there is a wonderful record of him meeting Handel the composer and you think you know you can go off in enormous flights of fancy about what these two great minds must have had to say to each other. Handel was writing the creation, you know, Herschel was talking about star formation. You can imagine the conversation but unfortunately from Handel's diaries we know all they talked about was the amount of money that you could make by writing for local churches.

So he was supporting himself as an astronomer and himself and his wife, in fact Caroline Herschel were in their spare time doing astronomical observations and this is one of the more significant results. I know it doesn't look like much or perhaps looks like an early biological drawing but this is a map of the galaxy that Herschel made. He had the idea that all he had to do was count the stars in each field, he could see through his telescope across the sky and then that would give him a map of the galaxy.

In fact the method is complete rubbish. What you actually map is the dust distribution. You can't see the edge of the galaxy with the telescope that he was using. But you get the idea that the galaxy is a disc and that is genuine. There are more stars out here than up out of the plane. He placed us at the centre, were actually displaced but that's no too bad. And in fact if you follow the theme of trying to establish that there were other galaxies onwards, like the ultimate amateur telescope is this one. This is a remarkable devise called the Leviathan of Parsonstown, in Southern Ireland; not your natural choice for an astronomical observatory it has to be said, the weather is terrible.

This was built by the Earl of Ross who hit upon the idea, he was essentially making a lot of money out of steel manufacture and he cut a deal with his workers that they could have an extra day a week off if they spent half of it constructing what was the world's largest telescope. It is a very clever design because he realised that the hard thing with a telescope is producing a mount which lets you swing around the sky. The Earl of Ross realised that if you have the largest telescope in the world you are not going to be short of things to look at. And so this telescope can't really swing from left to right, it can only go up and down supported by these giant walls and he just waited for objects of interest to pass across: very, very clever.

At the time, the big debate was about how many galaxies there were. Obviously we were sitting in what we know as the Milky Way. But the question was, "are there diffuse patches of light that they could see around the sky, are those other Milky Way sized things at a great distance or are they just gas? Are they nearby patches of nebulous material?" Of course we now know today that many of them are distant galaxies.

This is a particularly nice example, this goes by the romantic name of M51. Astronomers this will be a theme - should not be allowed to name anything.

I was giving a talk the other day about a newly discovered rocky planet around another star. You can imagine this being another world with a surface we could stand on and it goes by the name of CoRoT-7b. We need some help I think.

Anyway so this is the modern image what I wanted to show you was Ross' drawing of this object which we can superimpose with any luck, there we go. And not only is it pretty accurate but the important thing at the time that it shows the spiral structure and it also, he also was able to resolve individual stars. And so by seeing that some of these nebulous patches were made up of stars he greatly increased the size of the universe that we were considering. Suddenly, not only do we have one spiral galaxy with a 100 billion stars in it, but we have many, many galaxies.

So, these are all amateur results in some sense but clearly they are expensive efforts whether we are talking about Will Hay who funded his observatory through the proceeds from his music hall career or whether we are talking about the Earl of Ross subsiding his work in the manor of the Victorian Grand amateurs or indeed whether we are talking about people like Anthony Wesley the discoverer of that spot on Jupiter today.

We are talking about people who are putting a large amount of time, effort, education into taking part in science. They may be amateurs because they happen to do other things but they are operating on a professional scale.

So, one of the things that we were interested in is trying to find a way to lower the barrier of entry to science, to doing science not learning about it and that's something that I think our project has achieved. But before we get onto that, let me set up the ridiculousness of the situation that we found ourselves in. Never mind the Leviathan; it's entirely the fault of this telescope here. This is the Sloan Digital Sky Survey telescope in New Mexico. It's what happens if you let particle physicists build you a telescope. It was built primarily by a team out of the University of Chicago and 'Fermilab' when they decided that they should get involved in astronomy as a way of expanding the labs activities.

You know, a traditional observatory operates as follows. Most of the astronomers in the world will spend a lot of their time writing applications to use telescopes. For example, we have just had a whole round last week when I was applying to telescopes in Spain, in Arizona and to use the Hubble space telescope.

Typically a professional observatory will be oversubscribed by factor of about 10-20 from sensible, serious proposals. So a committee will select from among those proposals and you are very grateful for the few hours that you get. Two hours on the Hubble space telescope is immensely valuable. I have seen a PHD thesis written entirely based on the results of 37 minutes on an x-ray telescope.

So, we are very grateful of what you get but you turn up having had to travel to horrible places like Hawaii in the process, it's tough but somebody has to do it. In fact the last time I was there the weather was so bad we didn't get up the mountain, I had to spend a whole week on the beech but it was horrific (laughter). And then I got to go back as well.

Anyway, you turn up and you make the most of every single second. You point only at the objects that you have carefully justified in, the observations off and you do not waste any time. Then the next person comes in and you hand over and so on. Sloan is different. Sloan is more of an experiment than an observatory. A group of people got together and decided that all they wanted was an image of and a position of about a million galaxies and they would worry about sorting out the weak from the chaff from doing the statistics and so on later.

So, Sloan just literally just scans across the sky allowing galaxies to drift across its electronic camera, imaging each one for a total of about two minutes and it did this for seven years, producing in total images and positions of about a million galaxies. What that gives us is our first proper map of a large chunk of the local universe. Now a million galaxies is an insignificant fraction of the whole. We think in our observable universe there are about as many galaxies as there are stars in the Milky Way; so, 100 billion galaxies.

But a million is enough that we are sort of on the largest scales on which we expect anything to happen. We think that if we took this chunk of a million galaxies versus another million from over here or another million over here or another million here, they would look roughly the same. Obviously, you would have different patterns but the statistics and the structure would look much the same.

Let me plunge you into darkness for a second because these results are actually worth it. I am going to show you an early release from the Sloan. We are going to start on the Milky Way and then we are going to move outwards, away from our own home galaxy throughout the Sloan. We are looking at an early release, so this about half a million galaxies. So, about half of the complete survey and something interesting happens. We start on the Milky Way and we move outwards and I know this looks like every science fiction film you have ever seen but this is real data, galaxies in their correct position. Somewhere around now something interesting happens.

You start to notice that the galaxies aren't scattered randomly through space. Ignore the stripe down the middle that is just an artefact of the direction in which we are looking, but you can see that there is a sort of honeycomb structure emerging. In fact, on the left there, there is a bow shaped feature running about half way down the image. That is the largest structure we know of in the universe. It is called the Sloan Great Wall and it is two billion light years across. For those counting that is about 10 to the 25 metres. It is an enormous thing and on these scales you find that the galaxies aren't smoothly distributed. This is apparent colour, so they are getting red here because of the effect of the expansion of the universe.

Well we will stop in a second and rotate our three dimensional map of the local universe and you will really get a sense of what we call this cosmic web, this honeycomb structure. What we would like to do is to try and make sense of this diversity of structure that we see. We are going to zoom outwards and this is now going to put the Sloan in context versus the edge of the observable universe. The axis here is light travel time and you can see actually we have a fairly insignificant chunk of the observable universe measured but it is good enough for most purposes.

I will let that keep running in the background. We end up in the office of the people who made the animation I think.

So, what model can we use to try and understand this? Well, in some ways we think we have got the basics sorted out. We start with an expanding universe, in this case contained in a Chicago office I think. But we have an expanding universe which began in or at least was in hot dense state 13.7 billion years ago and we actually know that number more accurately than we know the age of the earth.

If there are any geologists in the universe, any geologists in the room, I presume there were some in the universe. I haven't observed any recently, so I am not sure but if there are any geologists in the room please take that as a personal challenge. I think it is a disgrace that we know the age of the universe better than we know the age of the earth.

Anyway, we have this idea of an expanding universe and the evidence for that comes form the work initially of Edwin Hubble over in California in the 1920's and this is his original data plotted on a modern axis. So, you can think of this as millions of light years. This is kilometres per second of recession because we see all of the galaxies receding from us. Each dot is a galaxy, if you are an economist this looks like a perfectly straight line.

To an astronomer this is pretty good data as well. To anyone who has worked in a science where it is easy to do laboratory measurements here is the modern version from the Hubble space telescope and we now have hundreds of millions of light years covered. Tens of thousands of Kilometres per second and we have this apparently very strong and hard to explain relation that the further away a galaxy is the faster it appears to be receding from us. It is this one fact that gives us the idea that space is expanding.

To see why that follows as a consequence, the only way I can ever get to this is to think about this painting. This is by the Dutch artist Esher; he was as bad at naming things as astronomers are, so this is called Cubic Space Division because it divides space into cubes. But what I want you to imagine is that we are all sitting down here on this cube in the bottom left and that in this universe that we find ourselves in, all of the rods are expanding at some constant rate, lets say 100mph.

So how would that look in this strange universe? Well the first thing is that obviously all of the cubes would appear to be receding from us. We would deduce that we were at the centre of the expansion because all of the cubes were rushing away from us but so would anyone on this cube or this cube, or this cube and so on. So we would see all the cubes receding from us and in fact we would see this one from up here heading in that direction at a 100mph, just because of the expansion of the rod joining us to it.

Now the one in the top right would be heading in the same direction but would appear to be receding twice as fast because this rod is expanding and so is the rod up there in the top right. So, it would appear to be receding at 200mph. If you were careful and you did your observations of these other cubes, you would conclude that the further away a cube was the faster it was receding from us. It's trivial; it is just because there are more rods joining us to the distant cubes.

Now if you replace the cubes with galaxies and instead of having rods expanding you have space expanding at some constant rate. So for every chunk of space that expands at a particular velocity, then you have the idea that the more distant a galaxy is the more space there is between us and it and therefore the faster it will be receding. We can recover Hubble's Law just by letting space expand.

We can also run this movie backwards in our minds and instead of having expanding rods, as you go back in time the rods are contracting and you quickly get back to a point where all of the cubes are crushed up on top of each other. This moment we call the 'Big Bang'. We can talk about what the universe would have been like back then. In fact for reasons I don't have time to go into, we can actually measure tiny fluctuations in the density of the universe back then. We think that it was pretty much uniform but there were tiny fluctuations on the order of a few parts in one hundred thousand, places that are slightly more dense than the average and places that are less dense than the average. It is these tiny fluctuations that become exaggerated to produce the cosmic structure that we saw in the Sloan moving.

I can show you that with a computer simulation. For example, we start the simulation 300,000 years after the big bang, we run forward to 15 million years and we stopped it here. Where you see bright patches, these are regions that are denser than the average. Where you see dark patches, these are regions that are less dense than the average and so you can predict what is going to happen, we have got a small blob here maybe one part in a thousand more dense than the dark patches to either side. Any material nearby will feel the gravitational pull of this blob and tend on average to move down into the denser regions of space and that has the effect of exaggerating these tiny fluctuations.

So, the rich get richer, you know the places with more stuff have a stronger gravitational pull, pull in more material and what starts as quite a smooth field from 15 million years to one billion years, to five billion years and then to today becomes quite exaggerated. We have this web structure that you saw in Sloan. You can see it much clearer if I run it forwards as a movie.

I have taken out the expansion of the universe to make it easier to see but you see what starts off as a smooth distribution of matter ends up as this cosmic web. In some sense this model provides an explanation for the structure that we saw. You can pretend that you were sitting in the centre of this cube and had a telescope like the Sloan and you can ask how many Milky Way sized blobs there are in your field of vision. What the largest structure you should expect is. How big the biggest voids, the areas without any material in are and so on. We get the answers pretty much right. On a large scale we understand the formation of the structure that we see.

In some sense we are done, modern astrophysics is finished. We have a model that fits; I don't get to go to Hawaii anymore. Don't tell, I know the head of department of physics, Roger Davies is coming later, don't tell him that we were done; I still want to go to Hawaii.

But in another sense the model that we use is profoundly unsatisfactory. To get this right the recipe I put together for the universe is a little distressing. Let me show you, this is a pie chart that splits the distribution of the universes energy, its energy density today and 0.03% of the universes energy density is in the form of what an astronomer would call a heavy element of metal, anything other than Hydrogen or Helium. So, to an astronomer, Carbon, Oxygen, nitrogen is all metals. It drives chemists absolutely up the wall.

So, 0.03% everything we actually care about as humans, our planet, everything we are made off. 0.3% is in the form of fast moving particles know Neutrinos. 0.5% of the universe, the universes energy density in the form of stars. We are deceived by looking at the night sky with our eyes. We see these wonderful sparkling things that pick out the shapes of galaxies and yet we don't realise that we are only looking at 0.5% of the universe.

What's the rest? Well, 4% is in the raw materials from which stars could form, hydrogen, helium, gas which probably will eventually go on to form stars. That gives us the total of about 5% of the universe in forms that we understand. The remaining 95% of the universe presents a profound problem. 25% of the universes energy density in the form of something called dark matter. This is stuff that has gravity, that doesn't interact with light and we infer its presence indirectly.

For example, if I don't put dark matter in, then the process of exaggerating these tiny fluctuations happens much slower and we end up with a universe that is too uniform today. We also need dark matter to hold spiral galaxies together. We can see how fast the galaxies disks are rotating and without the presence of a lot of, without six times as much matter as we can see hidden there, the galaxy would fly apart.

So, 25% of the universe is in this form of dark matter, we blame the particle physicist's, they need to discover a massive neutral particle and then we need say that there is six times as many of these as there are ordinary atoms. They tell us this is feasible. Hopefully the large hadron collider in turn will produce some candidates for this dark matter. It is embarrassing but between friends I think we can get away with dark matter.

The real problem comes in the other 70% of the universes energy density, which is in the form of something that goes by the hideous name of dark energy. When this was discovered this was a fifth fundamental force. We are used to as physicists explaining everything by four forces, gravity, the electromagnetic interaction and then two nuclear forces. However, we discovered in the late 90's that much to everyone's surprise the universes expansion is not slowing down but is speeding up and none of the four forces can possibly be responsible for that speeding up of the universes expansion, so we have to invent another force and we call it dark energy.

The British astronomers involved wanted to call it quintessence which is nicely classical; it was the fifth element of the Greeks, the fifth force. The Americans named it and they called it dark energy. The rumour is that it was because they wanted to try and get funding from the US Department of Energy by claiming that 70% of the universes energy is in a form that we can't even understand let alone tap. A manoeuvre that has proved remarkably successful, it has to be said.

Anyway, the point is that we have no idea what form this force takes. We don't know how it behaves, we can measure its strength today but what we need to do, if we are going to understand the fate and the composition of the universe is look back and see whether it has changed. How it has affected the formation of galaxies and the universe we see today. Now to do that is hard because if we just compare the simulation I showed you to the observations, I said we would get all the answers right so how can we get more information out of these simulations? How can we produce new challenges to that theoretical model to help us look for places where we can get information about dark energy?

Well one way to do that and this was the inspiration behind Galaxy Zoo is to realise that I have pulled the wool over your eyes slightly when I say that this simulation matches that beautiful fly through the universe. I turned the lights off for the flight through the universe because it is worth it whereas this is just blobs. All this simulation knows about is the behaviour of matter. It doesn't care about star formation, it doesn't worry about chemistry and it doesn't worry about producing galaxies that actually look like galaxies. Things like this.

I said that it gets the right number of Milky Way shaped sized blobs, not the right number of things that look like the Milky Way. So one way to interrogate these simulations is to say, okay, we know we have spiral galaxies and we have elliptical galaxies. We have merging galaxies and we have warped galaxies. We have all sorts of things. If I can record in the Sloan where the spiral galaxies are, suddenly my computer simulation needs not only to get the behaviour of matter right, it needs to get the history of star formation right, it needs to get the history of galaxy interactions right, it becomes a much more stringent test. All we have to do to impose that test is to classify the galaxies that we have in the Sloan survey and there we go.

Luckily, there is a well known classification scheme, Edwin Hubble again, he called it the tuning fork diagram and essentially it splits elliptical galaxies from spiral galaxies. He thought it was evolutionary sequence, he thought you started off here, the gas cloud collapsed into a disk, which then formed spiral arms and then the arms wound themselves up. That is complete rubbish but it turns out this division is quite profound. It tells you about the dynamic state of the galaxy, elliptical galaxies tend to be more massive, they tend to reform stars earlier, they tend to have been formed from collisions of galaxies, whereas spiral galaxies are homes of most of the star formation in the universe, they tend to be solitary, they live in different parts of the universe.

This division is as fundamental as that that you have come across as a medical researcher trying to understand the behaviour of a disease without realising that humans come in two flavours, male and female. You absolutely need to know what galaxies you are dealing with. The only problem is that we have a million.

In the 50's when the larger sky survey was a few hundred galaxies, professors would deign to classify galaxies. There are big atlas's published telling you that professor who ever it was, thinks that this galaxy is a type E4b subclass 3 spiral / elliptical.

In the 80's we were up to thousands of galaxies and that's fine because you can get a grant student to look at a thousand galaxies. With a million it's rather difficult and we needed to look at new ways to do things. One way to do this is to use a computer programme. That is expensive, you have to run it locally but it has a more fundamental flaw. Computer programmes will get 70% – 80% of the galaxies right. This sounds pretty good until you realise that the 20% that they get wrong are selectively the unusual ones and they are the ones that contain a lot of the information.

All you find out from computer programmes is that most elliptical galaxies look like this and most spiral galaxies look like these, well that's fine but we want to find and correctly classify the 20% that tell us more about this border and tell us more about the formation of these things. So we couldn't use a computer programme.

What we did know about was a programme called 'Stardust at Home'. Now Stardust was the space craft you can see up there on the right, that flew passed this potato shaped object, this is comet Vilt 2, the nucleus and had this amazing detector made of airogel, the lightest material that we have every created and the airogel would capture particles from the comet and then the space craft returned to Earth. It landed safely and what you ended up with was if you take a thin section of this airogel you can see here there is an entry point and there is a track and then there is a dust grain sitting here and they had something like a couple of million dust grains.

If you want to study the comet that's fine, you can take a random sample. Amongst those millions of dust grains they thought that there might be ten or so that came from beyond our solar system. It was a chance to get our hands on pristine interstellar material. The only problem is that you have to decide which ten they are. You would like to take them all out and look at them all in the lamp but the procedure to extract the dust grains is complicated and expensive. Instead they needed somebody to review pictures like this and look for things that are unusual. So they put this on the web and 20,000 people spent a lot of their spare time looking at dust grains.

We knew about this and I thought well surely if people would look at dust grains they will look at pictures of galaxies, so we created the Galaxy Zoo website. You turned up, you took a test. I know six year olds can pass the test because they have emailed me. I know at least one professor of physics who failed it, so I think we got the level about right (laughter). Then you get the galaxy drawn randomly from the million and a set of buttons, is it an elliptical or a spiral? If it is a spiral tell us which way the arms are rotating. There is also a star button and one for merging galaxies.

This was launched in July 2007. We actually launched it on the 'Today' programme. We got followed up by the BBC News website. If you have ever seen the BBC News website it has a little applet a ticker that tells you which stories people have emailed to each other. So on launch day we were there, we were second. Scientists seek galaxy hunt help, just behind 'Man flies to wedding a year early', some news is really important. We were still there later in the day just behind 'Huge dog is reluctant media star'. To my eternal regret I didn't click on that so I have no idea what that story was about but it anyone remembers from two years ago please let me know.

The effect was slightly stunning; this is our performance in the first two hours since launch. A couple of things to notice, you will notice that there aren't really any classifications of the first twelve hours or so, this is because the computer that powered the site caught fire here (laughter). Our team at John's Hopkins unbelievably built us a new web server in eight hours, thus getting the project back on line. In this time we received 20,000 emails from people, most of which said, "did you know your computer was broken?"

But it was very successful; let me give you some scales. The largest professional classification when we started was Figriguitaetal, three people, 3,000 galaxies each.

I have to confess we tried the easy way; we did give the problem to a graduate student. His name is Kevin Schawinski, he is now a post doc at Yale having decided that the Atlantic Ocean between us and him is a good idea but we are trying to name the unit of galaxy classification after Kevin because he did 50,000 in a month, so the Kevin month is there. Incidentally the first result in Kevin's thesis was that a graduate student will look at 50,000 galaxies before telling you where you can stick the other 950,000.

Anyway you can see we were doing a ridiculous number of classifications and this carried on. We didn't quite maintain this pace but in the first two years of the project we had a quarter of a million people and more than a hundred million classifications. Because that means that many people have looked at each galaxy we can take an average, we can listen to the majority, we can do things, weighting users depending on their behaviour, how well they do compared to professionals, to each other and instead of just having a million galaxies we now have different pots.

I have electrical galaxies, I have spirals with clockwise, and I have spirals with arms going one way. The direction of arms tells you about the rotation of the galaxy, so all of these rotate clockwise. All of these rotate anti clockwise. We have got edge on spirals where you are looking along the disk. We have got some alien space craft and we have got merges there in the middle. They are not really alien space craft, I said that in a talk the other day and I was submerged at the end by people wanting to know how they got their hands on this data. The point is that this works and we were able to classify our galaxies.

Let me tell you about some of the things that we have done with that. The first thing is that we were able to show quite how important it was that this was done by eye because looking at these two, these are typical examples of their class, typical spiral, typical elliptical and they are almost stereotypical because if you ask an astronomer to describe a typical electrical galaxy, the stereotype is that they are old red and dead and the stars in them are old, there is very little star formation going on.

Wherever you see blue stars in an astronomical image you are looking at massive stars that are quite short lived so we know that there was star formation here in the last couple of hundred million years or so, because the blue stars are still there. In the elliptical they have all died out. There is very little gas so very little star formation going on.

Some had argued that you should split galaxies by colour, you know lets just have blue galaxies and red galaxies that would be the same as spiral and elliptical. You don't need to look at them you don't need to put anything on the web but the first we showed is that is actually not true. For example on the top here you have got a typical blue spiral galaxy from Hubble, they are different galaxies but an example from Hubble and an example from Galaxy Zoo on the right you have got typical ellipticals. Hubble and Galaxy Zoo and in the middle you have got an example of a spiral galaxy, there are clear spiral arms there but the colour is the same as the elliptical.

We find a whole series of spiral galaxies and in some environments they account for about a third of the galaxy population which are spirals where the star formation has been turned off. In fact they seem to have undergone a process which meant that we are not allowed to name things, has the technical term of gentle strangulation because what's happened is that these galaxies form in the middle of nowhere out in the field less dense regions of the universe and have dropped in to the environment of a galaxy cluster, encountered denser material which has stripped away the fuel they need to keep star formation going.

Now that story was known but what people didn't realise that this process happened so gently that the spiral arms are left in tact and so now we have a challenge to the simulators, they have to make this process happen without disturbing the galaxies. Later on these galaxies will probably plunge into the centre of a galaxy cluster, a much denser region, at which point they will collide and form an elliptical. So we don't see any red spirals in the centre of galaxy clusters because by then they have had a much more violent encounter.

Speaking of spirals, the first thing we tried to do was supposed to be a sanity check to show that our data was acceptable. We had these two types of spiral, clockwise and anticlockwise and there was a paper by Michael Longo of the University of Michigan and Michael Longo is a wonderful bloke but one of those people if you gave him a baseball bat and a beehive it would be a matter of seconds before he applied one to the other, just to see what would happen.

He published a very controversial paper which claimed that he had looked at 3,000 spiral galaxies and he found more anti-clockwise spirals than clockwise, to some degree of statistical significance and this, it is hard to explain quite how controversial this result is. For starters, it is an observation that depends on your position in the universe, if you travel. Imagine all galaxies to me appeared anti-clockwise, then if I was on the other side looking back, they would all appear clockwise. We assume in cosmology that any observation we make on the large scale doesn't depend on your position in the universe, so there is that problem.

Secondly, you have got the problem of how galaxies separated by many, many, many billions in some case, a couple of billion light years, know that on average they are all suppose to go anti-clockwise. When we started talking to theorists about explanations for this and the kind of thing they would turn around and say is well, that makes perfect sense if the universe is small and shaped like a donut or if there is a universal magnetic field that we have ignored until now. It was a really nasty horrible result.

So we thought that all that had happened was Longo hadn't looked at enough galaxies. If you think a coin is slightly biased, tossing 3,000 times might not be enough to tell you whether it is really getting 50/50 heads or tails or whether something else is going on. We had a quarter of a million spiral galaxies at the end, so we thought we could make this result go away and to our absolute horror we found to something like eight sigma that 52% of our sample were this and 48% this. It doesn't sound like a big difference but with that many galaxies, it was a hugely significant result, which worried us.

We thought that we should be careful so we put mirror images into the database without telling anyone. And so if the result is real what you should now expect is more clockwise galaxies than anticlockwise and we don't. We still see 52% clockwise and 48% anticlockwise. It is not, the problem isn't in the stars but in us. It is us that are odd. There is something about human perception that makes you more confident about seeing spiral arms, if they look like this than if they look like this and it turns out that this is almost a well know psychological effect. Well at least it is with moving images.

I have an example; this is known as the ballerina illusion. How many of you see her rotating clockwise? Peer pressure is a wonderful thing. How many see her going anticlockwise? A few brave soles. How many have seen her switch in the time? Good, excellent. So if you take a lot of people and a lot of time, you see, over a lot of time there is a preferred direction in the population as to which way this ballerina is spinning. Apparently if you know about ballet it is absolutely obvious but you assume that no-one knows anything about ballet.

We think that we have got the static equivalent here. There is something about the perception of movement in these things. People are interpreting in them as spirally down into the screen there. So, we are now writing a psychology paper on this effect because we had a really large sample of unbiased data. We are even looking to see whether it's different in cultures that read right to left as opposed to left to right. It is a beautiful spin off project and it has produced beautiful science as well.

I have talked about red ellipticals; sorry I talked about red spirals. Thought I should talk about my own piece of this research which is to look at the opposite, blue ellipticals because ellipticals present a fundamental challenge to the model. We think the galaxies build up by the addition of small blocks.

If you look right back as the Hubble space telescope has done to the beginning we see small faint, gas rich galaxies. Maybe a 100th of the size typically of the Milky Way and over time we expect these to merge together so that you build bigger and bigger galaxies and so you would predict from this simple model that the biggest galaxies would be forming today because you have got to add together many, many blocks, have many more merges. And the biggest galaxies are ellipticals but what we actually see is that most ellipticals formed in the early universe.

So this is an example of something that we just don't understand. What we wanted to do therefore is find the stragglers, the few ellipticals that are still forming stars today, study the process locally and use that to interpret what was going on in the early universe. So we have a sample now of blue ellipticals, remember blue means star formation. So each of these is forming stars at something like 1 to 50 solar masses of gas converted into stars per year. And a typical spiral galaxy like the Milky Way forms about one sums worth of gas into stars per year.

We have our sample; we went to measure the amount of fuel they have for star formation using this place. This is the IRAM 30 metre telescope in Spain. I promise it is a great observing site; the fact that it is in a ski resort in the Sierra Nevada has nothing to do with the choice to go there. But this is capable of looking at Carbon Monoxide, the second most common gas in these galaxies and we get something interesting. I know it is a technical graph, this is my work, you can put up with it for a minute and then I will move back to more general things.

For each of these galaxies we have the time since recent star formation began on a logarithmic scale and we have got the amount of molecular gas, the fuel for star formation and at 200 million years after the beginning you see there is a sudden drop, we don't see any galaxies with substantial amounts of gas after this point. And 200 million years is interesting because this is the point at which the black hole at the centre of these galaxies begins to have a say in proceedings.

We know that there are black holes at the centre of most massive galaxies. The one at the centre of the Milky Way is about 2 million times the mass of the sun. We know that, in the Milky Way's case because we can watch things orbit it. This is a real image of stars at the centre of the Milky Way, observed over the course of about ten years. And you can see that they are all orbiting and it is an amazing technical achievement to be able to see this. You can see that they are all orbiting something that appears to be here and because we know the mass of the stars we can calculate the mass of the invisible object at the centre, just in the same way that we can calculate the mass of the sun by looking at the behaviour of the planets.

So we know that there is a black hole at the centre of the Milky Way and ours is pretty much quiescent. You don't see any light coming from it, there isn't a large amount of material currently falling into it. But it turns out that black holes are polite creatures and have a maximum rate at which they like to feed and if you try and force material onto a black hole much faster than this critical limit, it will build up into a disk, an excretion disk and then all sorts of other phenomena happen and in particular you can get large jets.

So this is the large elliptical galaxy M87, we have zoomed in on the centre and you can see that this is in the radio; you can see a jet coming out from the environment around the black hole at the centre. These jets can have a profound effect on their environment. In our case of our blue ellipticals, we think they heat up or expel the gas, the fuel for star formation and switching off the formation of the galaxy. We think this process has long been suggested that this process has a crucial role in the early universe. We have never been able to see it happening. Now with this local population of galaxies we can study in detail what happens when a black hole turns on, in a star forming an elliptical galaxy.

Another place where we were interested in black holes is probably our poster child, our most famous object. One of the amazing things about this project has been that people have been willing to get involved not just in clicking on galaxies and answering the questions we ask but in doing their own research. The simplest way to do that is to find something unusual and this object is a good example. When I ask a computer to classify this galaxy it will tell me that it is a spiral, it doesn't show up very well but there are dust enshrouded spiral arms here and move on. If you show this to a person they start muttering about Kermit the frog or whatever else you happen to see down here.

In fact the first person to see this was a Dutch school teacher called Hanny Van Arkel and she emailed us about it describing it as a Voorwerp. Does anyone speak Dutch? Excellent my pronunciation was spot on. Voorwerp we thought was a technical term so we called it Hanny's Voorwerp; it turns out to roughly translate as 'thingy'.

But I am proud to say that we now have this object in the scientific literature as Hanny's Voorwerp, our big challenge now is that we need to find more than one of them because I want to get the plural which is Voorverpen into the jargon but we haven't. This is a unique object and it is a bit of a detective story. Hanny told us, we didn't know what this object was, we phoned some friends who were on, and observing around on a telescope in La Palma, the William Hershel telescope which is UK ran. They have to calibrate their camera and their spectrograph at the start of every night so they accidentally pointed the telescope at this patch of sky to do the calibration. It was a remarkable coincidence shall we say.

That gave us our first data and that date told us that this is a blob of gas at about 15,000 Kelvin, so reasonably hot. Which wouldn't be that mysterious expect that we also found that there were no stars in this object, no source of heating or ionisation. So we were trying to work out why this blob of gas should be so hot. In fact we now know that there is a whole lot of cold gas out here and it is only this blob that is shining.

The culprit is up here, the obvious suspect is still on the scene. There is this galaxy here. If this has black hole in the centre and it probably does, if that black hole was active you might expect a jet to come out in this sort of direction and that jet is to be powerful enough to ionise and heat this gas. It is a simple enough story, to confirm it and to get our prosecution of the culprit, all we had to do was look at this galaxy in the x-rays, a typical sign of black hole activity which can't be hidden by the dust in the galaxy is x-ray radiation.

We pointed an x-ray telescope on the Swift satellite at this object for 5,000 seconds, which is quite a lot for one of these observations and we got three photons in total. In other words there was no detection at all. So the black hole isn't active. What we think we have got here is a galaxy in the act of switching from being an active galaxy to a quiet one like the Milky Way. We know this happens because we see the population of galaxies change over time.

We see that there were more active galaxies in the past but we have never been able to catch one in the act, but we think that that is what we have got here and we have Hubble space telescope time to go and look at this object.

I can't resist showing you are more recent example as well. Lots of these things come to us through our forum; whereabouts 15,000 people discuss what they have found. I know this doesn't look like much but this is an example of an object that our users called a Galaxy Zoo pea because it is small round and green.

There is a whole thread for discussion on the forum in which people made terrible puns about peas. And then the rule became in order to participate in this exciting game you had to find one of these in the background of a galaxy that you were classifying and eventually they had a few hundred of them and asked us what they were. We didn't know. We were busy.

At which point a group of our users, none of whom had scientific training went deeper into the data. We provide access once you have classified a galaxy to the professional data, just for fun they looked at spectra, they downloaded the relevant data, they wrote database queries, we used to get the information they needed and they came to us with essentially what was a pretty good fourth year astronomy project. Better than lots of the stuff I have seen from under graduates here announcing the discovery of this new class of galaxy.

We followed it up, we published the paper with them as co-authors and we have discovered that these are the sites of the most active star formation in the local universe. There are galaxies converting almost all of its gas very suddenly into stars. So we have this interesting population of galaxies that we don't understand at all.

When you look at them with the Hubble space telescope a few of them happen to be in the background of Hubble images, lots of them look a bit like they might be merging, particularly these two at the top. We don't know if that's a coincidence. We don't know if that is structure we are picking up, it is very, very tricky. But the point is that we have, these peas have been in the data sets since the 60's but no-one looked at them, so no-one noticed how unusual they look, no-one had time to go and do the digging through the spectra to see whether they were really interesting and we have now got a whole army of volunteers who will do those things for us. This is happening again and again.

We said naively that we didn't care about our regular galaxies the blobby ones that don't have, they are interesting but they are a side show. A group of users decided that that was completely unacceptable and have gone away and I have got the draft of their paper on elliptical galaxies on my desk. It is perfectly submittable; the top six or seven authors on the paper will be non-scientists.

We have discovered this mode of working enables people to contribute by clicking, to move on by discussing in scientific way what they have found and even to take part in and run their own research projects. It is very different from the normal model where people get told stuff until the beginnings of their PHD where suddenly they are scientists and can only then contribute.

We are doing further projects. We have Zoo 2 which has got 40 million classifications since February. This is getting to know the galaxies a little better by answering a whole series of questions. We have more detailed images of some of the sky, thanks to repeated visits from Sloan, just a couple of weeks ago we switched from images that look like this to more detailed images that show up all sorts of fine structure.

But looking ahead we would like to continue to involve the public in what we are doing. In fact we are going to have to and the thing that keeps me awake at night at the minute looks like this. This is the large synoptic survey telescope. It is not under construction, I have seen the mirror. `[[And SST 0:53.48]]` as big as the largest telescopes in the world today. It is about 8.4 metres across the mirror but it is designed to do something very different. It will scan the entire sky every three nights. Partly to look for things that move but also to continually build up a deeper and deeper image.

To give you an idea we are talking about 30 terabytes of data per night. So if any of you are computer savvy then you will understand that that's a lot. To give you an idea, if I wanted 30 terabytes today, the best and most efficient way for the observatory to send it to me would be to fly somebody over here with a suitcase about this size of hard drives. We don't even know how to handle this data.

So, let's be sensible, let's say that all we care about is, let's use a computer programme to do most of the work and to get the computer programme to spit out interesting changes that have happened since the last observation. That maybe is more sensible. Well we think that will trigger 100,000 alerts per night.

What we need is the following, we need a computer programme that can do most of the work for us, but it must also not just make a guess at what an object is but it will need to decide whether that object should be passed to human volunteers for inspection. It needs to have some sense of whether it is right or wrong and when it is uncertain. The idea is that that will go on to the web, people will look very quickly at the results from this, probably within a few hours so that anything that is worth following up they can pick up on.

We are even talking about partnering with some of the global networks or robotic telescopes to enable the volunteers to do the first step of follow up. So if it is interesting they can take control of a telescope, go and get the spectrum, go and get measurements in different colours to see how it is behaving, so that we can make use of the data and so that as professionals we are not overwhelmed.

Because what we are looking at is really a flood of data and we don't have many years to get ready for it and it is my contention that without involving large numbers of members of the public from around the world most of this data will be thrown away and we will miss out on discoveries like the Voorwerp and the Peas as well as being content with classifying correctly 60 to 70 to 80% of our data. Whereas the interesting things the blue ellipticals, the red spirals and whatever their equivalents are will be lost in the rest of the data.

The other thing is that, sorry this is my idea of how man and machine are going to work together very carefully with this algorithm working with the volunteers. What is interesting though is that as we have developed this project it has become very apparent that it is not just astronomers who are having these nightmares and so in the next few months we will see the launch, not of Galaxy Zoo but of what we have decided with a straight face to call the Zooniverse. A whole universe of Zoo projects which will take, yes future astronomy projects.

We have partnerships with NASA to look at planets so just, I don't know how many of you saw the news about water on the moon this week. The moon is a fascinating place attracting a lot of attention. In fact the new satellite that you can see there, Lunar Reconiscience Orbiter, it is a NASA satellite that went into its final orbit just a couple of weeks ago. It is sending us 80 gigabytes of image data a day. Again it is too much even if all the worlds planetary scientist did nothing but look at the images they would never be able to see the images at their full resolution and this thing can resolve features on the lunar surface that are about this size.

You may have already seen the images of the Apollo landing where you can see the astronaut footprints, not individually but you can see the track. Similar capabilities exist on Mars, this is an avalanche in progress on the Martian surface, there is a slope from left to right, you can see that there is a shinny patch of ice here where material has broken off and has rumbled down hill. You can see the line of the avalanche and then this dust cloud.

Now watching this sort of dynamic process on another planet tells us a huge amount about how the Martian surface changes over time. But this was only discovered because they happened to print this image out for a public display at some ridiculous resolution and put it up and somebody was walking along and said look, it is an avalanche and when they looked closely there were hundreds of these on the same image, that is one image out of something like 30,000 that have come back from Mars in the last couple of years. Most of the rest haven't even been looked at in this detail.

If we are ever going to do that, if we are going to make serendipitous discoveries, if we are going to classify the craters on the surface on the planets which give us the age of regions, we are going to need help. We have NASA involved and Moon Zoo will launch sometime in the next six months and then we will move onto other planets. That probably still astronomy.

We have partnerships particularly in Oxford, so in the top right you have two new Caledonian crows; these are famous for being extremely clever. Well they are Oxford crows so you might expect that. But in the lab here they turned out to be able to create tools, they would bend sticks carefully to enable them to break into food containers, it is a nightmare if you are trying to keep these things. But the question is do they do this in the wild or is this learnt behaviour?

They have gone as far as, we know that newly born crows seem to develop this ability; it is not just learnt from their parents. But obviously in the laboratory setting you never quite know what they are picking up. If they ever start using Wikipedia then we will know that they have least been monitoring. Actually we would like them to classify galaxies because that would make everything very nice.

The point was do they do this in the wild? So the researchers a few years ago took a camera, went down to New Zealand and set it up in a forests glade and sat and, sent a student, there is a running theme to this and sat and watched as the crows travelled across the forest and they saw crows without sticks, they saw crows carrying sticks, they saw crows hop on carrying bent sticks but they never saw a crow actually produce the tools.

Now they are going back to do a proper effort because cameras have become very cheap. Band width has become very cheap; it is possible to scatter the forest now with cameras. They are even going to attach cameras to some of the crows. But how do you look at that data? A huge amount of effort has been put into face recognition technology and tracking people on CCTV and it is really hard, the idea that you can do this for crows for a one off application is far fetched.

Instead why not spend your breakfast looking at a nice New Zealand forest glade and there is a button if the crow does anything interesting, so we will be working with a whole set of ecology researchers.

We have oceanography projects in partnership with the Maritime museum. One example I like is it turns out that a restriction on the climate models is that most of the data pre 1900 is in the form of ships logs which haven't been transcribed. If anyone fancies sitting at home and reading the journal of a captain sailing the South Pacific, great please come and do that but type in every time he mentions the weather and then that data can actually be used to improve our forecasts of climate change.

My current favourite example comes from the Satlclar library in the department of classics. About 100 years ago, just over now, an amazing team of Oxford archaeologist went down to a place called Oxirincos in modern day Egypt. It was a Greek settlement now abandoned and they found the rubbish dumps of this abandoned town, which were stacked in some places 25 feet deep with ancient papyri. Which would presumably some sort of proto recycling scheme, all the papyri was sat together. In fact the soil was so rich that it was being excavated and used as fertilizer because the papyri were decaying.

In a desperate effort to save it, Granvel and Hunt, the people involved brought back to Oxford something like 6 million fragments of papyrus carefully stacked between copies of the Oxford university gazette, in the absence of them. Why they took copies of the Oxford university gazette to Egypt I have no idea. Presumably they didn't want to miss out on what was happening at home.

But most of these boxes haven't been opened. A huge scullery effort has transcribed a few percent of the papyri. We have no idea what is in the rest of the boxes. The existing 2% has yielded a couple of extra gospels, lost works by a whole host of classical authors. Unique early versions of works by almost everyone you have ever heard off. It is our only large set of manuscripts from the classical world and for those of you that are more interested in social history rather than literary history, 90% of it, is letters and documents and you know, dear Nigel please send me three crocodiles next time the Nile floods, all of this stuff.

But no-one has looked at it, so we are going to put it on line, most of it have been imaged and do two things. As people to, the hard task is to transcribe this text, it is just about doable if you have multiple transcribers because you catch each others errors but also by recognising things like the spacing between the lines and the arrangement, we can put together fragments by the same author. At least the scullers will have the ability if they are working on one fragment to pull down all the rest of this collection.

We have all of these projects, all of which involve lowering the barrier that people have in participating in research. When we have done a survey, most of our users tell us the major motivation is they want to contribute to research. They are interested in galaxies, sure. What they want to do is just do something useful with their spare time instead of watching television primarily.

We have a model where you don't need to have gone through formal education to do science, even just clicking produces a result that ends up in a scientific paper and we can, I think produce an active and engaged population of working researchers, whether they are looking at crows, papyri, Mars, the oceans or heaven forbid even some galaxies.

Thank you very much.