Hi, everyone. This is Chris Britt from NASA's Universe of Learning. I'd like to welcome you all to this telecon today. Thanks for joining us, and anyone listening to the recording in the future. Now for this August science briefing, we'll be talking about the deep fields, Shonda and Hubble uncovered the growth of early galaxies. Slides for today's presentation can be found on the Museum Alliance and NASA Nationwide sites. For all the recordings from previous talks should also be up on those websites. And as always, if you have any issues or questions now or in the future, you can email Jeff Nee at jnee@jpl.nasa.gov. And that's jnee@jpl.nasa.gov. Museum Alliance members can also contact them through their new team chat app. And info for that is on the website. So we have a panel of speakers here today. So I'll introduce them briefly as they come up. And you can read their full bios on the websites as well.

So to start with, let's welcome Dr. Garth Illingworth, who's currently a distinguished professor emeritus at the University of California in Santa Cruz, but was formerly the deputy director of the Space Telescope Science Institute, and former deputy principal investigator for Hubble's Advanced Camera for Surveys. He was also one of the leading members early on in the James Webb Space Telescope mission development, which started 30 years ago, this year. So Garth, please take it away.

Thank you very much, Chris. Hi, everyone, delighted to be able to give you some insights into the amazing images that Hubble takes, but also what we do with them to learn about the earliest galaxies in the universe. And the first slide actually has one of Hubble's, I would say, most amazing and interesting images. This is the deepest image of the sky ever taken by any telescope. And as I will explain, as I go through this, this is really a history book, a story book of galaxies growing in the universe from some 13 billion years ago. Let's go to the next slide.

And the next one shows us the wonderful image of the telescope. Hubble, of course, in the last servicing mission. The space shuttle on the astronauts went up, and on the right hand side, you see an astronaut carrying a very large box, it's a pretty sophisticated and large version of the camera that's in your phone. And that will be put into Hubble. And that will open up a whole new window on the universe for us. And this was the last time that we actually had a chance to go to Hubble to do any of this work. Since then, of course, Space Shuttle has completed its missions and we're working on Hubble now as it was in 2009. Hubble is now 29 years old and going strong. So it's a great telescope.
[Slide 5] And the next slide, you see Hubble floating in space, moving away from the space shuttle, the last close up view that we have of Hubble. And since that time, we've been working and collecting wonderful data.

Dr. Garth Illingworth 3:10

[Slide 6] And if you look at this slide, there's actually three telescopes there. These are, NASA's great observatories. So what I'm going to be talking about today, and then what Belinda will talk about, are these telescopes, and one of the many, many things that they do. So Hubble is sort of the fundamental one that we're using to probe the early universe for galaxies. But we have also done a huge amount of work with Spitzer, as I'll mention later, and then Belinda will tell you about Chandra and its accomplishments as well.

Dr. Garth Illingworth 3:44

[Slide 7] So let's go on to the next slide, which I think is number seven. And now I'm coming back to this extreme Deep Field image. As I mentioned at the start, it's the deepest Hubble image ever taken. 10 years of Hubble data were put together to make this image. Basically it's 2 million seconds of exposure. When you take an image with your phone, the shutter clicks for a hundredth of a second. So imagine what you could collect if you sat there pointed at one region of the sky for 2 million seconds. And that's what this image is. And you see there large numbers of faint fuzzy blobs. These are all galaxies, Milky Way-like galaxies and others far, far away. In fact, we're using our telescopes as time machines. These galaxies are so far away, the light has taken 500 million years, a billion years, five billion years, and in one case, 13 billion years to reach us. So we're looking back in time to when those galaxies emitted that light, that is 13 billion years ago. So we have our time machine, showing us the various galaxies at various stages of development.

Dr. Garth Illingworth 4:57

[Slide 8] And if we go on to slide eight, again, I always emphasize that this image, and images like this from Hubble, are really a history book. It's a story of how galaxies formed and grew, through nearly all of time, the universe is about 13.7 billion years old. And in this image, there's one galaxy, which is about 13 billion years. So we're looking back through 95%, 96%, of all time to see that galaxy. But of course, there's thousands of images here, some much much closer. And so we're looking at galaxies a few hundred million years back to 13 billion years back.

Dr. Garth Illingworth 5:37

[Slide 9] If we now go on to the next slide. So I was showing you the deepest ever image of the sky there, the XDF. In the middle of this sort of complicated figure, you see a little cyan square that says XDF in it, that's the size of a typical image from Hubble. But we haven't just been pointing the telescope at that region, and building up the images, what we have done, is that we have moved it around and built up a bigger mosaic, a bigger array of images, a bigger image.
And the white outline actually showed that bigger image. The green circle, as I think Belinda will talk about, is the Chandra Deep Field South. So here we are, where we're incorporating or having available X-ray data. Over this region too, of course, is data from the Spitzer Space Telescope, the infrared data. So we're putting together a remarkable data set here. And as the little box on the left, says, somewhere between 6 and 7 million seconds from each of these telescopes on this region. That means there's something like about 70 or 80 days of collecting light, with the shutter open, as it were, during that time. So this is a remarkable image, because it's enabled us to find many more galaxies. There's well over 200,000 in this one.

Dr. Garth Illingworth  6:58

[Slide 10] If we go to the next image, we can get a sense of how big this is on the sky. And you all look up and see the Moon and it's a tiny part of the sky. We're basically learning about the whole of the evolution, the history of galaxies, from just a few regions about this size. This is the best of those regions, there are some others but a tiny part of the sky. But it's given us probably, maybe half a million galaxies that we are now using to study these very distant objects. But it's a very challenging thing to do this.

Dr. Garth Illingworth  7:34

[Slide 11] So if we go on to the next one. I'll give you a sense here of what these individual galaxies look like and what we know about how long ago, we have seen them. In the upper left, it's 500 million years ago, that galaxy that may be somewhat like our Milky Way seen edge on. Then as you go to the right, and then down, you see the galaxies they get further and further away, they get messier, a little blobby looking objects in the middle, and then they get to be very tiny and very reddish, as the light is red shifted to us. And at the bottom right, you see this very faint little blob. It's 13 billion years ago, this galaxy, only 500 million years after the universe was formed. As I said, looking back through 95% of all time. So we have a remarkable time machine here that's giving us insights into how galaxies formed and grew.

Dr. Garth Illingworth  8:29

[Slide 12] Now let me, on the next slide, show you the most distant galaxy we have found so far. Strikingly about five years ago, we were looking at one of these regions on the sky, and we noticed these four reddish blobs, and that's the column labeled Hubble there, you see four reddish little blobs, basically, that's what they are. Then on the right is images from Spitzer, which doesn't have Hubble's acuity. The images are not as sharp, but they're amazingly valuable information. And we were astonished to find these because these four objects look to be about 500 million years after the Big Bang. But we tried hard to understand a little more about the brightest of those.

Dr. Garth Illingworth  9:15
[Slide 13] And if you look at the next slide, number 13. You see you an expansion of one of them, the one labeled GN-z10, which we actually found out, when we looked at it with Hubble in a lot more detail, we would call GN-z11. It was even further away and closer to the Big Bang. This is the most distant galaxy ever found, and probably about the limit of what Hubble will ever do. And we were astonished that we were seeing a galaxy back almost to cosmic sunrise. Cosmic sunrise is were the first stars and galaxies turn on in the universe. And we know that there's probably around a few hundred million years after the Big Bang, but we know almost nothing about it. And so our big hope there in investigating that is not with Hubble, or with Spitzer or Chandra or any of these, we really need to push out with a new telescope.

Dr. Garth Illingworth 10:11

[Slide 14] And if we go to the next one slide, I can't even see what that is, 14. Anyways, the one with the amazing purple and white images in it. This is a wonderful image. However, it's an artist's impression. We can't look at this time at the moment, in the lower left is an image of what we expect the James Webb Space Telescope to look like when it's launched in two years, moves out beyond the Moon and starts to observe. And one of the things that we have talked about for 20 years with this telescope is seeing first light: first stars, first galaxies. So we will not see the detail in the artist's impression. But we really hope and I expect that we will probe back into that time, and see some of the very first galaxies forming about 300 million years after the Big Bang.

Dr. Garth Illingworth 11:02

[Slide 15] And so let us go to the last slide here, number 15. And it's just a beautiful image, a conceptual image of the James Webb Space Telescope. And I note there 2021 is the beginning of a whole new era. We're going to launch this cold, large telescope. And we will be working and trying to understand what the very first galaxies in the universe are looking like. So in many ways, I call it our "cosmic sunrise" telescope.

Dr. Garth Illingworth 11:31

Thank you very much, Chris. Thank you.

Dr. Christopher Britt 11:36

So I think we'll have a question period, kind of after both of the presentations. So just go ahead. I'm sorry, I thought somebody was speaking. Thank you, Garth. So we'll save the questions till the end. And for now, let's give a warm welcome to Dr. Belinda Wilkes, who's the Director of NASA's Chandra X-ray center, and senior astrophysicist at the Center for Astrophysics at Harvard, and Smithsonian. And as I mentioned, you can see everyone's bios in full on the websites. That is kind of the quick highlights if you want to learn more about who the speakers are. So please feel free to take it away, Belinda.
Okay, thank you. Good afternoon, it is a pleasure to be here today to speak about Chandra and the kind of science that Chandra is doing in the X-rays. I'm the director of the Chandra X-ray center. And the X-ray Center provides science support and also operations for the observatory, which is the world's premier X-ray observatory.

I was speaking to slide one, so going to slide two Garth already show you the NASA great observatories. And I wanted to put Chandra in perspective with the others. So I'll just quickly go over what he said earlier. In order to see everything in the universe, we need to look at multiple wavelengths. And what I'm showing here is the four great observatories. CGRO is gamma ray and is no longer operating. But we have Chandra, Hubble and Spitzer. And the temperature scale shows you the range of temperatures that each of those looked at in terms of the material. So if a material is cool, it'll emit in the infrared. If it's a normal temperature that we're used to, it will be in the optical and Hubble will see it, and also go to the UV. And Chandra looks at very, very hot material. Below that is just an indication of the wavelength of the light that we're looking at in each case. So to get a complete view, we need multiple wavelengths of observatories.

On slide three, I give you an idea where X-rays come from. So why do we need to look in the X-rays. The X-rays originate in the hottest, and most violent and most energetic places in the universe, and, I argue, the most exciting as well, but then I'm biased. Some of these places are hard to see in any other way. That gas is really really hot, and emit in the X-ray, you wouldn't be able to see it with any other telescope than Chandra or an X-ray telescope. So Chandra has actually turned its X-ray eyes to all kinds of celestial sources, and has opened up the X-ray universe as never before. And the main reason for that is the exquisite spatial resolution that it has.

And on the next slide, I'm losing count of the number of slides, I think it's number four. I'm showing the Orion Nebula, which is a star forming region. And this is a picture taken with ROSAT, which was the previously highest resolution X-ray telescope. And you can see that it's draws a smoke in the middle. It has an order of magnitude worse resolution than Chandra as it's a half arcsecond, and ROSAT was about five arcseconds at its best. And so with ROSAT there were 100 sources and in the very center, you can see they all blur together, we just can't resolve them, there are too many sources close together to be able to see them all individually.
[Slide 20] The next slide number five shows what this field looks like with Chandra. And we're now at 1,400 sources. And right down in the center while the very bright sources look big, because the wings of the primary section is quite bright, you can still see other stars sitting right next to them. This is star forming region, you may be familiar with it, it's in the middle of the dagger of the Orion constellation. It's very bright in the X-rays with all these sources that you can see young stars are unstable, violent places and strong X-ray sources. We're able to find them with Chandra, which will be much harder with optical and infrared observations. Because there's a lot of material there, there's gas and dust that's falling in due to gravity and forming these stars. And it's very hard to look through gas and dust in the optical and the infrared. The gas is falling in together, some of it falls into the star to form the star, some of it can't get in and gets blown out, and hence the hot and unstable place that we have until the star is finally formed. However, today I'm going to be talking primarily about supermassive black holes, which are very strong X-ray sources. These are situated in the center, the supermassive ones are situated in the nuclei of galaxies, galaxies just like our Milky Way and like the ones that Garth has just been speaking about.

[Slide 21] But active galaxies actually have a supermassive black hole, which is accreting a lot of material from the galaxy around. And that material gets very, very hot. And in fact, the nucleus outshines the rest of the hundred billion stars in that galaxy. And this artist's impression shows a stomach angled view of what we think the structure of a quasar looks like. It's a very bright core, you can just see 'cause it's an almost edge on view, we have jets, so many of them going perpendicular to the structure that we're seeing, and there's an image in the radio and the X-ray, and then this hot material in the center. And then as you move further, the material gets cooler. So you can actually see from this artist's impression that if we were looking very edge on, you just would not see the bright core in the middle. And that's going to be important later on. So this is an active galaxy or a quasar. Most of what we see when we look at deep fields with Chandra is supermassive black holes that are active.

[Slide 22] And on the next slide, the actual main aim, main motivation of designing the Chandra X-ray telescope was to resolve the cosmic X-ray background. This was a diffuse X-ray signal that was all over the sky in all the previous X-ray missions. It was seen everywhere, wherever we looked. And as the missions got a little bit more powerful, some of those were resolved back into individual sources, but not all of it, there were still diffuse emissions. So we wanted to be able to look so deep that we could either resolve it all out, or decide that it was diffuse. And this is what we were able to do with Chandra and the Chandra Deep Field South, which is the same field, I believe, that Garth was showing you before, but in the X-rays. And on the right hand side, this is what the field looks like. And you can see that it's full of point sources. They're dots of light, they're not smudges, like Hubble sees. Hubble is looking at galaxy emissions and it has a size. These are point sources because the nucleus outshines the rest of the galaxy. This image looks as though the sources in the middle are smaller and/or fainter than those on the
edge. That is actually an illusion, it's not realistic in the sense that the point spread function degrades as we move off-axis. So a bright source sitting on the edge of the field will look larger, it will look as though it has a size, as a smudge, but it's, in fact, unresolved at that level. So they look brighter.

Dr. Belinda Wilkes 19:02

[Slide 23] And just to show you that we do have as many sources in the middle, I'm going to zoom in on the next slide, I'm showing a yellow box.

Dr. Belinda Wilkes 19:10

[Slide 24] Now I'm going to zoom in on to that part of the image. And you can see that there are just as many point sources in the center of this field, it's just that they were smaller dots in the previous version. I'd like to note that we have about 1,000 sources in this field, mostly supermassive black holes that are active. 50,000 sources per degree squared, this is the deepest X-ray image ever taken. We're looking back about 12 to 13 Gigayears, so to about 10% the current age of the universe almost as far as Hubble has seen but not quite. The colors in this image indicates how red or blue in the X-rays the target is, a source is. So something that's blue in the optical mean that it's pretty hot in temperature and the photons have high energy and something that's red is cooler in temperature like your barbecue coals when you've just lit them as opposed to when they're blue or white hot and you can cook on them. And so we see in this picture I've now zoomed in and I'm not sure which slide I'm on. So without the yellow box, the next slide, we see very many different colors. So we're actually seeing sources that are hot and the X-rays so very high energy in the X-rays and sources that are lower energy in the X-rays. You see that for some reason, Chandra is very good at finding supermassive black holes.

Dr. Belinda Wilkes 20:35

[Slide 25] On the next slide, I show the standard survey wedding cake. As Garth was saying, we can study only small bits of the sky in great detail because it takes a long time. The Deep Field for Chandra is 7 megaseconds of observation time taken over a number of years, that's about three months, but it takes a very long time to get to that depth. We can't do that over the whole sky. So what we do is we take a narrow deep field, then we do medium depth, wider surveys and then very shallow, much wider surveys. So I'm showing you here, roughly what we have currently with Chandra. We have the Deep Field, which is 480 square arcminutes, we have medium depths, we have about two square degrees to only about 200 kiloseconds, rather than 7 megasecond depth. And then we have about 40 square degrees and 6,000 sources in the very wide field. And that way we can get a picture of a population. Even the rare sources that you wouldn't see in a very narrow, deep beam, you can find in the shallow wide beam. So we can study the whole population of a certain type of source, or many different kinds of sources.

Dr. Belinda Wilkes 21:48
[Slide 26] In the next slide, I'm showing a figure from a paper. So this is a scientific figure, which I will explain, but you only really need to know to look at the red and the blue dots. We study the population and we also look at their evolution. And this plot is showing the number of sources as a function of that brightness. And on the right hand side - in two energy bands. So the left hand side is the lower energy, right hand is the higher energy. And the brightest sources on the right of each plot that you can see there are very few that are very bright, you look at the red curve now with the red points, and then as you go to fainter fluxes there are more and more sources. The same is true in the higher band plot, the higher energy plot. An interesting thing that we found in this deepest field is that when you look at the very faintest fluxes on the left hand side, on the left hand plot, the blue points are now higher than the red points. Those blue points are galaxies. So we're actually now finding that there are more galaxies at those very faint fluxes than there are supermassive black holes. These are galaxies without active supermassive black holes in their core. They probably have supermassive black holes, but they're not active. There are many more of them than are the active kind. And these will be much nearer to us, because they're much fainter X-ray sources. So we're seeing them, but they're much nearer to us not at 12 or 13 gigayears away.

Dr. Belinda Wilkes 23:12

[Slide 27] On the next slide, I'm showing you - Garth talked about being able to look back in time as you look at something at more distance, it's actually younger than the things that are closer to us. And the plot here is showing, as a function of age, the number of sources we see. And so basically on the right hand side, things are very young, and you've got the blue and red points on the red dash curve, showing you how many galaxies there are. These the galaxies now. And then as you come towards the present day, so moving to the left, there's a peak, where the universe is about an age of three gigayears, and then they decrease again. So most of the galaxies in the universe are situated at the distance, which corresponds to an age of 3 gigayears, or a redshift of 2, which is the typical unit we use. The black curve shows you what the supermassive black holes do. You can see they peak at pretty much the same redshift, the same distance from us. So what we have found with these surveys is that they peak - the number of entities peak at the same redshift, which raises the question which we still haven't really answered as to whether supermassive black holes and stellar growth, so that's the star formation in galaxies are actually directly related whether they really work together directly, or whether they just happen to be using the same gas to form. We still haven't answered that question, but they clearly do seem to be growing in concert. At the very young ages, it does seem that galaxies start with a star to make the galaxies shine do start earlier, and that supermassive black holes start a bit later, and then more of them form more quickly. But beyond that, they're really very similar.

Dr. Belinda Wilkes 25:02

[Slide 28] And the next slide I'm coming back to the artist's impression of what a quasar looked like. And just to remind you that the edge on view is very obscured, particularly in the optical and near infrared.
And on the following slide, I'm showing you the number of sources that are obscured as a function of that redshift. So again, the young ones are on the right hand side, the old ones are on the left hand side, this is a plot from the Chandra Deep Field South, and you can see that as you go to younger sources, more of them are obscured. And what we think is happening is that as the supermassive black hole forms in a young galaxy, it's enshrouded by a lot of material that is busy forming stars, and so we can't see it to begin with. And it's highly obscured. And then as time goes by, that supermassive black hole blows out a lot of radiation that pushes away the gas and the dust until then we're able to see the active nucleus.

And then I'd like to point out that this is an X-ray survey, of course, it's with the Chandra X-ray telescope, the X-rays are able to see these obscured sources much better than any optical or near infrared. However, we're still biased in the X-rays against those that are very, very edge on. We still lose some of the X-rays in the very edge on sources, where you're looking through that system material. In the artist's impression I showed you [X-rays] are about 100 to 1000 times fainter. So one way to solve this is to combine X-ray observations with radio selected quasars, pre-selecting the low frequency radio, we actually see these targets at all orientation angles, because we're looking at radio emission which is coming from material much further away than the nucleus, optically thin and we can see it from all directions.

And so what the plot, I'm showing you here on this next slide, is shows us that the obscuration measured in the X-rays and the orientation measured in the radio correlate very strongly. The edge on sources are highly obscured on the left hand side, top left. The face-on sources, where we're looking right down into the nucleus are not very obscured, and they're in the bottom right; those are the quasars in this plot. We actually find a fraction of obscured sources, which is about 50%, and 20% are absolutely edge on, what we call Compton-thick sources, that's a much higher fraction, then is found in the X-ray survey directly.

So I just like to finish with one little story about this first target we looked at which was a source to focus on, as I noted, these active galaxies, or quasars, are point sources. So they're very good for focusing your optics. So we went to a distant quasar, called PKS 0637-75, to focus, and it's six billion light years away; it's quite far away. But what we saw instead of a point source, which you're seeing on the left of this image in blue, we also saw this expanded emission on the right hand side, which is the elongated, and this we were not expecting. It actually didn't prevent us from focusing the telescope, but the people in the control room looking at this, the first thing we looked at, were very concerned that there may be a problem with the telescope, that one of the mirrors could be misaligned, or something could be in the beam scattering some of the X-ray away. However, in fact, what's happening is that this as a target
has a radio jet. And this X-ray feature actually lies right on top of the radio jet, so what we discovered in this first observation was that radio jets emit very strongly as well, in the X-ray.

Dr. Belinda Wilkes  27:42

[Slide 33] This is actually an emission called non-thermal synchrotron radiation. It's not because material is very hot, it's because the electrons in that material are moving very, very fast around the magnetic field lines so they emit in the X-rays as well as the radio. And that's all I wanted to say. So I'd be happy to answer any questions. Thank you.

Dr. Christopher Britt  29:21

Thank you, Belinda. So I'd like to go ahead, before we move on to the educational resources that we've lined up and go ahead and open the floor to some questions for the science speakers while the science is still fresh, if that's all right with our hosts. So if anyone has any questions, I'll be looking at the WebEx. And so here's one that was asked to Belinda. Can black holes remain dormant for a period? Can they be awakened?

Dr. Belinda Wilkes  29:56

Yes, the short answer is yes. We believe from - the evidence that we have shows that all galaxies have a supermassive black hole in the core, it can range in the size from the millions to billions of solar masses. So it's a pretty wide range. They sit there for a long time without being active, but then something will awaken it. It could be, for example, that two galaxies merged together and lots of material is channeled down into the center. And once it gets close to the black hole, it moves around it, making a disc-like structure that I showed in the figure. And because all that material is trying to pull into the supermassive black hole, that all gets in each other's way, and it gets very, very hot. And hence we get this emission, a very bright emission, actually in lots of wavelengths, all the way from the X-rays, down to the mid to near infrared. So what we think is happening is that most supermassive black holes have active periods that maybe last a million or ten million years, and they are quasars in active galaxies at that time. And then at some point, they'll calm down again after the merger, or whatever triggered this activity will slow down, and they'll stop emitting for a while. And then something else may happen in their future that causes it to start again.

Dr. Christopher Britt  31:21

Thank you very much. So the next question, I think, is for Garth. Has Hubble now seen as far as it can?

Dr. Garth Illingworth  31:29
Yeah, I think that's probably the case. Hubble has a vision that goes out into the near infrared, a little longer than what our eyes can see. And these distant galaxies are moving so fast that all the light is redshifted, moved out into the infrared. And James Webb was conceived and designed to be a telescope that can work in the infrared. So James Webb will pick up where Hubble runs out of steam, as it were. So I think we're pretty close. Or we may well have seen the most distant galaxy ever with Hubble, but in two years, we'll unveil a huge number more with James Webb.

Dr. Christopher Britt  32:10

Another question for Belina: are there citizen science projects associated with Chandra?

Dr. Belinda Wilkes  32:18

Not really, we tried thinking about doing that. But in actual fact, we get very few photons in the X-ray compared with the optical, for example. So they're actually very few images where we can actually see structure that has the right sort of patterns, or enough signal so you can see patterns, that somebody from the public could actually make decisions on, for example, what kind of galaxy that was or what kind of shape that source was. So we haven't been able to come up with citizen science projects, yet, with the Chandra data.

Dr. Christopher Britt  32:58

What excites you the most about the JWST coming online in a couple of years?

Dr. Garth Illingworth  33:04

I think, ever since we started to talk about this project in the late 1990s, we called it the "first light telescope." Now just like Hubble, Hubble has worked on everything from the most distant galaxies to our solar system to planets around stars nearby. But to me, I would say it's the opportunity to explore that cosmic sunrise period when the very first galaxies are turning on. So we can see what's happening earlier time than any of our other telescopes can possibly, currently, can possibly reach.

Dr. Christopher Britt  33:42

And then the question is JWST still slated to be launched on an Ariane five rocket? And yes, is the answer that question.

Dr. Garth Illingworth  33:52

That's right in 2021, two years.
Dr. Christopher Britt  33:57
And then a follow up, do we expect that the surveys of the deep sky from JWST will illuminate the question of whether black hole formation and galactic formation are related?

Dr. Garth Illingworth  34:09
Let me answer and Belinda could also add to this one, too. I mean, I cannot answer that. I think this is a rather challenging question. Personally, I think that the fact that we see some active galaxies at very early times, so there must be big black holes there even in the first billion years suggest that black holes and galaxies sort of grow together. But actually understanding that, this is really challenging to do, because as Belinda has been mentioning, Black holes are really tiny. And so it's hard to get information on those scales. So I think we'll probably approach this indirectly by getting a lot more information from our observations, but then using a lot of computer modeling to try and understand what we see.

Dr. Belinda Wilkes  34:56
I can add to that. Yeah, I mean, with with Chandra, we're looking not quite as far back as Hubble, but almost. The JWST will look much closer to the birth of these galaxies and supermassive black holes, so we won't be able to see all of those with Chandra. However, Chandra is likely to last, we hope - touch wood - for another 10 years. But we would like to build a bigger X-ray telescope that will be able to look at the supermassive black holes in the JWST first light galaxies, and when we can get both that information - the infrared information, infrared observations - of what the galaxies look like at those high redshifts, at large distances, plus the emission we were seeing in the lower

Dr. Christopher Britt  36:13
Another question: if an X-ray source has a high redshift could the x-rays be shifted into the ultraviolet?

Dr. Belinda Wilkes  36:23
What happens with redshift is that blue light becomes redder. So when we look at higher redshifts, or larger distance, these massive backholes are actually looking into the higher energy x-rays that were emitted by that source and they then moved into our observing frame, which is lower energy X-ray. So they don't move actually. And the emission we were seeing in the lower
X-ray sources do move into the UK, so we're not seeing that anymore. I suppose the answer is yes. We're looking at a different part of the emitted spectrum, for the higher X-ray sources, we're looking at the harder X-rays, and the softer X-rays have moved into the ultraviolet.

Dr. Christopher Britt 37:04

And then there's a question about the black hole at the center of the Milky Way. Where does it fall on the scale of supermassive black hole sizes, is it especially large or small in comparison to other galaxies?

Dr. Belinda Wilkes 37:15

I'll take that one. It's pretty small. It's about 10^6, or a million times the mass of the Sun. And most of the supermassive black holes we're looking at in the X-rays are more like 100 million or a billion times the mass of the Sun. And the source, it's called Sagittarius A*, which is the supermassive black hole in the center of the Milky Way, this is actually not an active galaxy. It doesn't have continuously flowing material. It's not particularly bright. But it is a very popular target for Chandra, because it has these outbursts, which actually give us information as to how the dormant supermassive black holes work. So probably stars, or material around that Sag A* get a little bit too close to the supermassive black hole every once in a while and fall in. And then you see this burst of X-ray emission, coming from the supermassive black hole. And that happens quite frequently probably more than once a month. So we observe it fairly often. And we do so in concert, particularly with Spitzer. So we can look at those in the infrared as well as the X-ray. So it's still a very interesting place, even though it's not an active supermassive black hole.

Dr. Garth Illingworth 38:31

A very hungry beast of that eating a star every month.

Dr. Belinda Wilkes 38:36

Yeah, and that's actually not much, is it?

Dr. Christopher Britt 38:41

And there was a last question about what was meant by the term "confusion limited" on slide 25.

Dr. Belinda Wilkes 38:52

Yeah, my slides.
It was the wedding cake. Yeah.

That's right. As the point spread function is so sharp, that even looking for three months, the individual sources are not overlapping with one another, which they would be if they were confusion limited. Confusion means that the combination of the sharpness of your image and the amount of background that you're receiving, that is not related to the source you're looking at, causes the sources to overlap, so then you can't see individual sources. So thinking about the rest that picture of the Orion Nebula, for example [Slide 19], in the middle, that was confused. You couldn't tell how many sources were there it was just a smudge. In the Chandra Deep Field South we still are not confusion limited; we could look deeper. The problem with that is that we've looked for 7 megaseconds. And if we just looked for another few hundred kiloseconds it's not going to help very much. So to add something to that image, we'd need several megaseconds more. And that's a lot of time on a telescope. And the telescope is over-subscribed by at least a factor of five. So there are many more other pressing science questions that come along, that can use up those mega seconds. So we haven't allocated any time to look deeper on this field. But we could go deeper.

Let me just add to that. So on my slide 12, I showed four little red dots from Hubble. And then four images from Spitzer, the fuzzy blobs on the right hand side. Those images from Spitzer are really confusion limited. The images are so big, and there are so many galaxies that when you look at an image, all things overlap. And so we have to resort to very sophisticated processing to sort that out. But Hubble is almost never, in these galaxy fields, confusion limited. Only, say, in a star cluster or a bright galaxy where there's a lot of objects. So that's another example. When the images get very big, confusion sets in, and you have do some tricky data processing to sort that out. And ultimately, you can't sort it out because there's too much overlap, which is why we like big telescopes, James Webb is going to be great for that.

Thank you very much. And thank you all for your questions. So Rutu, are you on the line?

Hello.

Dr. Christopher Britt  41:25
Dr. Rutu Das  41:45

Thanks, Chris. Hi, everybody. We had two really wonderful talks, I'm really glad to be here to talk you through some wonderful educational resources, we have to go with all the topics you heard about today.

Dr. Rutu Das  41:59

[Slide 37] So if we go slide 37, just after the title slide, I want to start off - we talked about Chandra, and the Chandra Deep Fields here, we would like to commemorate the Chandra 20th anniversary, the exact date of which just passed a few weeks ago. So one of the resources we have for you is all of this information in celebration of the 20th anniversary. There is a website at the top of this slide. And this contains several resources, including an event calendar. There are talks, exhibits, and art installations, throughout the country. There are also several infographics and printables of varying sizes, some small, some fairly large. And there's a video on the website called "First Light." It commemorates the 20th anniversary and talks about Chandra's first light image.

Dr. Rutu Das  42:53

[Slide 38] If we move to the next slide, and this is slide 38. We'll start with our resources on deep fields. So on slide 38, you'll see the galaxy hunter activity. This is from the amazing space program from a few years ago. This lets users explore the Hubble Deep Field in a statistical way. So nowadays, a lot of astrophysics, especially cosmology, and especially a lot of the work we do with deep fields is not based on any single object. It's statistical. It's based on an ensemble of like objects. And this lets people explore that. So through this program, people can explore the different types of galaxies. And how many of each type of galaxy is in the Hubble Deep Field or perhaps in our universe. It explores concepts like bias, and sample size and other statistical concepts. It lets the user try a lot of different things and experiment like what if you took a smaller sample size? How would you count your galaxies? How do your results change if you have a larger sample size, and lots of different things like that, it also includes a bunch of background educational resources teaching to common misconceptions about the science, possible lesson plans if you have some time for a deeper, more in depth activity of several steps of statistically learning about the Hubble deep field.

Dr. Rutu Das  44:29

[Slide 39] The next slide, slide 39, we have a webinar called "looking out is looking back in time." This is the NASA's Universe of Learning webinar from last year; it's about an hour long,
and it talks about how we learn about the history of our universe, not just by looking far away, but by looking far back in time and how those two things are connected.

Dr. Rutu Das  44:53

[Slide 40] If we go to slide 40, his shows the Hubble Deep Field Academy. This is another way to explore Hubble Deep Field. This explores some of the same statistical concepts as Galaxy Hunters. But it also explores more about the classification of galaxies, talks about Hubble’s four different cameras and why the Deep Field has to shape that it does. It talks about how we determine distances to various objects in space. And again, it encourages the user to ask a lot of questions. Think Like a scientist. There are optional lab worksheets that people can fill out as if they are keeping a lab notebook observing the universe.

Dr. Rutu Das  45:36

[Slide 41 and Slide 42] If we move on to slide 41, this is a very new resource from Viewspace. It’s an interactive slider. So it’s called "Gathering Light" which was released very recently, a week or two ago. It shows how our astronomical images change based on the amount of time that we spend gathering light. So if you flip back between this slide and the next one, slide 41 and 42, you can flip back and forth. And you’ll see the difference. These are two points on the slider. Slide 41 shows an image with 21 minutes worth of gathering light and slide 42 shows 81 minutes. And you see the more time we take to image the area, the more noise falls away, the clearer our sources are, and it affects several other settings. So it’s basically visualizing exactly how the deep fields work. The longer we look at them, the better we can see our objects.

Dr. Rutu Das  46:35

[Slide 43] If we go on to the next slide, slide 43. So speaking of Viewspace, Viewspace has many different resources of videos, interactive sliders like this. Coming up very soon, in about two months is a Viewspace video library. And one of the key features of this is that you’ll be able to put in a keyword and Viewspace will create a playlist. So let’s say you want to just cycle through videos about black holes, or you want to cycle through videos about cosmology or the deep fields, you can put in these keywords and Viewspace will automatically pick up videos that are related to that and create its own playlist, kind of like Pandora.

Dr. Rutu Das  47:18

[Slide 44] Um, alright, let’s move on to slide 44. We have a few more looks at the deep fields. From Chandra we have several short videos and animations about looking at the deep fields and black hole growth within these fields. So here’s the first one: a quick look a Chandra Deep Field South. It’s a combination of the deep fields images, and some animations explaining what we see in this field.
[Slide 45] On the next slide, we have an animation showing black hole growth in this field.

[Slide 46] And slide 46, please. On slide 46, we have another video showing how early supermassive black holes grew in the deep field. All these videos that I just mentioned are a combination of images that are real data and animations that are artists’ impressions or simulations.

[Slide 47] So we can move on to the next slide. And more resources on details. We have some galaxy lithographs from Hubble. Each of these have wonderful images on the front. And then on the back they have information explaining these images and what's important about the science that they show.

[Slide 48] On the slide after that, slide 48, we have some more resources from Chandra about the deep fields. This is one section of the Chandra photo gallery. This is actually the cosmology section. So it includes deep fields, among other topics. But there are many, many posts on the deep fields. And some of them talk only about the Chandra deep field. Some of them, compare them to Hubble Deep fields and all the goods fields. This is for more information and interesting visualizations as well.

[Slide 49] Now let's move on to the next slide. By 49. We're going to move on to our resources about black holes, we talked a lot about black holes in the deep fields, and Chandra as a black hole hunter. We've got a lot of visual resources for this. One of the main things I want to point you to is the Chandra page on black holes, the link is at the top of the slide.

[Slide 50] If we go to the next slide, it gives a little taste of all the things you can find there. There's information about new discoveries, just the basics of black holes. It emphasizes Chandra as a black hole hunter. This is a very interesting section that talks about what did we expect to see when we first started looking, with Chandra, and what were the really weird, new things that were unexpected and we were surprised by, related to black holes, that Chandra found. There is a Q&A, general questions that people often have about black holes, and several podcasts and videos, and more animations. Some of these address common misconceptions about black holes.
Dr. Rutu Das  50:23  

[Slide 51] shows the Chandra's black hole photo gallery. It's analogous to the gallery of deep fields that I mentioned earlier. Again, the great thing about this is that you can see visualizations, not just from Chandra and in X-ray, but many of them compare to the same object viewed in different wavelengths as well.

Dr. Rutu Das  50:44  

[Slide 52] If we move on to slide 52, these are some principles about black holes. They range in size, some can be printed small, some can be printed as large posters, and we may have some of these actually somewhat poster sized to send to places if you want to contact us, you can contact me and I can look into this.

Dr. Rutu Das  51:11  

[Slide 53] If we go to slide 53 this is an activity about modeling objects in 3D modeling astronomical objects in 3D. And part of the activity - This is in tinker cad, by the way, which is an online software that lets you model interesting objects, it's very user friendly. And part of the activity, part of the guided activity is how to create an accretion disk. So it helps people explore the area around a black hole, in a little more hands on way, although still on the computer, not literally hands on, but more than just reading about it.

Dr. Rutu Das  51:52  

[Slide 54] talks about a couple of Universe of Learning traveling exhibit. So these are exhibits that you can you can borrow at any point they will be shipped to whichever center wants to borrow them, and then we'll ship them back. So for however long you want to have them up. And they don't particularly focus on black holes, but they include information about black holes somewhere in the exhibits. For example, "here there and everywhere" takes a look at, I believe, the black hole at the center of our galaxy. Astro Olympics also includes information about black holes as part of its exhibit. So you can look at these other traveling it's of it's on the Universe of Learning website.

Dr. Rutu Das  52:42  

[Slide 55] And can we go on to the next slide? I believe that's it for me. Yes. Thank you.

Dr. Christopher Britt  52:50  

Thank you. Any questions for Rutu about the resources here? Okay, says so, this will all be available on Museum Alliance. Yes, the the presentations and resource lists, I believe will be
there also available on the NASA universe of learning website under science briefings. And the transcript and audio will also be posted once they're available. Yes. So are there any special celebrations and programs planned for Hubble's 30th? birthday? Yes. Yes, there are. We're in the middle of those plans right now. So stay tuned. We're planning quite a lot. So watch that space. Yeah. Any other questions for Rutu to about?resources?

Jeffrey Nee  53:52
Yeah, Chris, this is Jeff. Yeah, so thank you very much, Rutu, I'd just like to tell you that the black hole FAQs have been really, really helpful for me personally, as an educator. So I think your team did a great job with that. And in terms of ordering, or requesting posters and stuff that you have in your warehouse? Should we just email you? Or should we go some other way? And if you want, the Museum Alliance can help you with that, if you're interested.

Dr. Christopher Britt  54:25
Emailing us, it's fine. Yes.

Dr. Rutu Das  54:28
Yes, email is fine. You can email me or there are several other people on the Chandra EPO list, Kim Arcand as well.

Unknown Speaker  54:37
If you go to the website that's listed on the slides, there's an email address that you can address, that's probably the most direct way to do it.

Jeffrey Nee  54:47
Perfect. Thanks, Emma.

Dr. Rutu Das  54:54
Useful, sorry,

Jeffrey Nee  54:56
Sorry go ahead.

Dr. Rutu Das  54:57
I just said, Oh, thank you. I'm glad the FAQs were useful. I'll let people know.

Jeffrey Nee  55:04
Yeah. And Chris, I just had more science questions if we have a few minutes left.

Dr. Christopher Britt  55:08
Yeah, I think we've got a few minutes left at the end for one or two more questions.

Jeffrey Nee  55:12
Great. Then I have a couple of hardware questions and a couple of science questions. The hardware questions. I think Rutu mentioned it a little bit about - I'm trying to find the slide. So if I go back to slide number nine, for example, for Garth, why is it so jagged? I get that question a lot. And I and I kind of waved my hand and make up an answer sometimes. But why are the fields so jagged?

Dr. Garth Illingworth  55:41
So that just reflects the fact that the Hubble image is small, so the XDF, one in there, the cyan images, is the size of the Hubble field, so as we move it around, it's very hard to fill out a nice square box. And so you end up with some edges that stick out. And also we occasionally we try to avoid very bright stars. So that indent in the bottom of the white area is around some bright stars, because that just saturates and scatter light everywhere. So it's just the fact that we're making up a mosaic from lots of little things.

Jeffrey Nee  56:18
Oh, I see. So the Mosaic, it's not one shot. And it's not like the shape of the detector, for example.

Dr. Garth Illingworth  56:24
Exactly, the detector is really only that tiny blue box. And so we have to scan around, and over the 16 years or so that we've been collecting these data, that's how it's turned out in that region. Thousands of pointings, in fact, we have seven and a half thousand different exposures in that white box to make up the Hubble legacy field.
So it could cause some confusion in that Hubble used to have a detector on it, WFPC-II, which did have a weird footprint. So the images from that era of Hubble's operations did have that kind of jagged corner on them. Because that was how the detector was shaped.

Dr. Garth Illingworth  57:12

Yeah, both the Advanced Camera and the Wide Field Camera three, the optical and the infrared, one are rectangular these days, pretty much. They are details in there but basically rectangular.

Jeffrey Nee  57:25

Great. Thanks. And I just wanted to double check my understanding with Belinda. When you talked about how the illusion of X-ray sources were brighter on the edges. Can you go over that one more time? Is that a property of the detector itself or something else?

Dr. Belinda Wilkes  57:44

The property of the telescope, actually, the mirrors. As you you look off axis, the point spread function, or the resolution of the telescope, gets bigger. So you can't resolve things. In other words, if you look in the center it's half arcsecond resolution. If you look further out, the point source will look like a smudge. It'll be much bigger than 0.5 arcseconds. Therefore, when you try to make a picture that shows that full dynamic range, the ones on the edge look as though they're much bigger and brighter than the ones in the middle. But it's simply because they're spread over more pixels on the detector, because the resolution isn't as good around there. Does that make sense?

Jeffrey Nee  58:25

Yes, thank you so much. I just wanted to double check to make sure that I understood that correctly. And then I know we're almost out of time. But I did hear a nice little interesting news article this morning about ALMA and and it's detecting a whole slew of new galaxies. Have any of you heard about that paper yet? And do you have any comments on it? And why it's so interesting.

Dr. Garth Illingworth  58:50

No, I haven't actually picked up on that so that we're very early galaxies. or

Jeffrey Nee  58:57
I only read the headline To be honest, I didn't have time to read through it. But we're detecting new galaxies all the time, presumably, is that accurate to say?

Dr. Garth Illingworth 59:10

Very much so. Very much so. If one of these fields is giving us new objects to look at, to expand our sample, but ALMA, because it's in the millimeter, brings us very dusty galaxies that are extremely hard to find and see with our optical infrared telescope. So in fact, it does open up a new realm for us, so that is another great telescope that complements Hubble and JWST, and Chandra, all these work together to add to our knowledge of galaxies and other aspects of the universe.

Jeffrey Nee 59:48

Thank you so much.

Dr. Christopher Britt 59:56

Okay, so if that's all of the questions, I think we're about out of time. So please thank our speakers for their time and joining us here today. And thank you all for coming and attending.

Dr. Garth Illingworth 1:00:13

Thank you. Very nice to have a chat to everybody.

Dr. Belinda Wilkes 1:00:20

Thank you.

Dr. Christopher Britt 1:00:21

Please remember that all of our talks are recorded and posted on the member websites. And you're encouraged to share these presentations as professional development with all of your colleagues, including education staff and museum docents. If you have any further questions about this topic now or in the future, you can reach us via the Museum Alliance team chat. And our next Universe of Learning telecon will be in October and stay tuned for that. The next Museum Alliance telecon will be on August 28th. With updates about the Goldstone Apple Valley Radio Telescope so hope to see you online at another time and the most up to date information on the telecons is on our websites. So have a good weekend and we hope to hear from you soon.
Thank you.

Thanks, everybody.

Transcribed by https://otter.ai and Jeff Nee.