NASA MUSEUM ALLIANCE
Hubble Science Briefing
Black Holes: Gravity's Relentless Pull
Dr. Roland Van Der Marel

Moderator: Anita Sohus
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Anita Sohus: Kay's at ASP so. I didn't even get to send it out to the Ambassadors. John you want to take it over?

John Stoke: Good afternoon everyone. My name is John Stoke with the Public Outreach Office here. I am filling in actually for Frank Summers who usually handles these, but he is, like Kay, he is off at the American Astronomical Society meeting, which is just concluding today in St. Louis.

Today we are very happy to have as our guest speaker Dr. Roland Van Der Marel. It is a tradition here when astronomers are announced, the first thing they always say, even if it was 30 years since they were in school where they got their PhD. I have no idea, and none of you really care.

Let me tell you a little bit about him however. He is an expert on black holes and some other things that he may talk about today. But our talk is about black holes.

And like many astronomers here, and he is an astronomer. That is his title, which is a lofty title in this place.

In addition to the half of his time that is devoted to scientific research and black holes and some other areas of galaxy science, he also serves as the lead of what we call the Telescope Group which is part of the Instrument Division. Am I saying that right Roland? Yes, for both the Hubble Space Telescope and its upcoming successor, the James Webb Space Telescope.

We, in fact, conducted a video interview just a week ago with Roland all about how the James Webb Telescope's many individual mirror segments will be aligned and the process by which they will be aligned so that they will function as a single coherent optical system.

Roland also has a great deal of interest in Public Outreach which is manifested in several ways and one of the ways you will learn about today is a Web site which he developed, a very informative Web site about black holes, which is also available to those of you who are in the Outreach business - the museums, planetariums or in fact Solar System Ambassadors.

We have a version of this Web site that is a standalone so that it can be run, operated for example, as a kiosk or operated off of a laptop without the need to have access to the Internet.

At this point I would just like to ask Roland to take over and start talking. We will click our way through the PowerPoint at least initially and I think…is it fine with you Roland for folks to just interrupt at any time chime in with questions?

For those of you who got the PowerPoint we are going to start. For those of you who do not, there will be a lot of words coming your way.

Roland Van Der Marel: Good afternoon everyone. Thanks so much for dialing in. This is Roland Van Der Marel speaking.

Let me start by saying that those people who did not find the PowerPoint, but do have access to the Web site, that is just fine. The PowerPoint consists primarily of screen shots from the Web site so you will not be missing anything if you just go to the Web site.

This is a bit of an unusual format for me talking to a telephone in an empty room. So to make it a little interactive, please do ask questions. What I had prepared to say may not be of most interest to you.

You may be more interested in other things that you have on your mind. Feel free to interrupt anytime. I would be happy to take questions on any of the topics.

And in particular, I will have to be a little selective clearly in the time allotted so I cannot discuss everything that is of interest in the area of black holes, so feel free to interrupt.

For those of you that do have access to the PowerPoint, on the second page there are a few bullets that I have listed there about why black holes are of interest to astronomers and also why they are of interest to the Outreach community.

In particular, they are sort of regarded as the rejects in the universe. And because of that, they really captured the interest of the public. People always ask about it. People always want to know about it. People always use them in science fiction movies and science fiction books.

The term black hole is used as a metaphor for many things in common language. So all of these things make that - it is really one of the things that, you know, people who have an interest in learning something about astronomy, quickly start talking about black holes when you give them the opportunity.

And people like you may be interested - where can we find information to maybe provide to people to answer some of these questions.

Black holes actually are associated with a large number of misconceptions. One of the main things to keep in mind when things come up is that, you know, people might actually come into the discussion with a quite poor view of what a black hole actually is.

Some of the misconceptions are that, you know, they are just sort of the topic of science fiction. They are not really based in reality. That they are sort of these giant vacuum cleaners that in a monstrous way suck in everything around them. That may be the Earth is in great danger because of some speeding black hole through universe.

There are good answers to many of these things. Black holes are not purely hypothetical. Astronomers have studied them for many decades and we do think they exist.

We can point to places on the sky where we think they are. We can weigh how much their masses are, and we can really study them.

We do not think they are giant vacuum cleaners among other things because a black hole is more like a Venus flytrap. If you happen to be speeding right to it, yes, you know, you may be doomed. But it is not that the Venus flytrap will suck in things from a large distance.

And it is the same with the black hole. If our sun were somehow magically to turn into a black hole tomorrow, it would get really cold on Earth, but our Earth would keep, you know, circling the sun on at one year intervals the same way it does now.

The orbit of the Earth would not change. It would not really be sucked into the black hole in any particular way.

Are black holes a danger to Earth? Well, we do not think so. We cannot really tell for sure because they are very hard to find so we do not really know what might be heading our way.

But even though there are billions and billions of black holes in the universe, the universe is a big place. The probability of one actually being a danger to us is almost, you know, infinitesimally small.

The nice thing about black holes is in sort of the Outreach context is that they provide an avenue to sort of grab people's interest and attention and then teach them other stuff that, you know, are associated with black holes.

When you talk about black holes, you can teach people about how people observe the universe and the world around them. You can teach them about the scientific methods. About how conclusions are reached and how hypotheses are tested.

You can teach them about the scale of the universe and the solar system and the galaxy. You can talk to them about sort of what typical things we find in the universe around us, and also that many of these things are not as mysterious as you are sometimes led to believe.

We can understand some of these things, you know, better than the weather maybe, in terms of predicting how they behave, and yes, they exist at scales and maybe temperatures that are different than what we are used to in our daily life, but that does not mean they cannot be understood.

I think it is a very important message for people that science does allow you to understand things with very basic laws and pure reasoning.

Black holes provide an avenue for teaching people about basic concepts such as light and gravity among other things which are the sort of the two defining concepts of a black hole.

Going to page 3 of the PowerPoint presentation, it mentions there that we have some resources available at the space telescope and those are the two things that were already mentioned by John. We have this Web site that of course everyone can pursue.

And there is also this free kiosk software that we can make available to, you know, any informal educational institution who wants to use this, run as an exhibit or for any other purpose. And people can actually contact John for this to get access to that.

Page 4 starts with going into the Web site. So for those of you who do not have the presentation, maybe you can go to the Web site page and that should start an animation that should start playing by itself, the introductory animation.

Well the introductory animation teaches people - it is sort of what a black hole is. And the idea here is that by just looking at the screen for one minute, you can maybe be convinced of the fact that these things are not quite so mysterious after all.

Maybe one of the misconceptions about black holes is also that they are made of some sort of very mysterious type of matter. And in fact, they are not.

You could take the Earth and you could turn it into a black hole, hypothetically. And the way to do this is you take the Earth and you squeeze it so that it becomes the size of about a marble.

If you could somehow do this, if you could have enough force and exert enough pressure on the Earth to do this and to make it that small, it would be a black hole. It would not be made out of any weird matter. It would not be dark matter. It would not be dark energy. It would just be the same matter than the Earth is made of. It would just be in a very small volume. And that is what defines a black hole.

If you stand on the surface of the Earth or any other object, you know, you cannot just get away from it very easily. If we want to get into space, we need to launch rockets at high velocity.

If you want to get away from the surface of the Earth, you need to leave it with some velocity to escape the gravity of the Earth.

The velocity that you need to have to get away is called the Escape Velocity. It depends on the distance you are away from the center of the body and the mass of the body.

The closer you are to the center while you are standing on the surface, the higher the gravitational pull on you is, the higher the velocity is that you need to get away, and of course the higher the mass of the object, the more of the velocity you need to have to get away.

What happens if you squeeze the Earth while you keep standing on the surface, then you reach a point where the velocity you would need to have to get away actually exceeds the speed of light.

One of the basic principles of Einstein's Theory of General Relativity and special relativity is that nothing actually can move faster than the speed of light.

You reach a point where nothing can ever get away from the object because you would have to move faster than the speed of light and you cannot, nothing can. In fact, not even light can get away.

That is where a black hole got its name. This was a term coined by John Wheeler, a famous physicist who just died earlier this year.

The black stands for the fact that light cannot escape from it. If you look at it from the outside, you will see no light. It will look black. The term hole may be a little bit more of a misnomer, but it means that once you get into it, you cannot get out of it ever again.

The important thing here is that maybe black holes are not quite so mysterious after all.

Now, of course, you need a lot of pressure and force to make the Earth that small. And in fact, there is no known force around us here that will ever do that. So we think.

And the same is true for the sun. So neither the sun nor the Earth, scientists believe, will ever become a black hole spontaneously.

But the interesting thing is this is not true for all objects in the universe, and in particular, as I will get to, very massive stars will become black holes quite spontaneously at the end of their lifetime. And that is one of the ways in which such objects form.

John Stoke: Any questions about anything so far? All right, you have got them captivated.

Roland Van Der Marel: Okay, I will keep going. This brings us to page 5 of the PowerPoint presentation and for those of you looking at the Web site, you should go into the Web site. It should say something like Enter, and you will see something that has a number of buttons at the top.

One of them is Journey to a Black Hole and underneath that it says finding the invisible. If you are at that, those should be highlighted in purple, you will look at a view of the night sky.

The idea here is to teach people a little bit about how we learn the things we think we know. And we learn in astronomy by observation, which means we look at the night sky.

One of the ways we have managed to learn about black holes, as mysterious as they may be, is by observing the sky in different ways. And this is an important conceptual thing.

Our human eyes are sensitive to regular visible light, which happens to be the type of emission that - where the spectrum of the sun peaks, and that is also why our eyes are so sensitive. That is where we have evolved towards.

But that does not mean that that is the only type of radiation that comes from objects in the universe.

If you look at the bottom left, it says X-ray and visible Light and radio waves, and you can click on these boxes and you can see certain objects on the sky as they appear in different types of emission.

There is this purple thing that says view. That is your viewfinder. You can drag that with a mouse. Put it for example on the sun, which is in the bottom left of the picture.

And then if you click on either X-ray or radio waves or visible light, you will see the picture of the sun change. And that is because the sun looks different in different wave lengths. Invisible light we just see it as yellow disk that we are all familiar with.

If you look in radio waves, you see these colored spots along the equator of the sun. Those are sun spots that are sort of hard to see in regular visible light, but are very prominent in radio waves because they have a different temperature than the rest of the surface of the sun.

If you click on X-ray, the sun will look even different. It will look like this glowing ball of gas where you can see particles escaping, magnetic fields breaking, and it looks like it is very violent object.

The thing to note here is that objects do look different in different wave lengths. And it also shows that if you look at different wave lengths, you tend to look at different physical processes.

If you look in X-rays, then you tend to be very sensitive to highly energetic phenomena that produce highly energetic particles, the type of particles that can disturb radio traffic on Earth for example, if there is a solar flare.

If you look in radio waves, you tend to look at the colder parts of the universe, at lower energy emission.

Now you can move this viewfinder over the sky and you will see various objects. You see the moon there. If you search you will find saturn. You can also click on the names on the right. So if you click on planets, your viewfinder will move to saturn. And again, you can view it in different wave lengths.

Now, the solar system is not so much of interest for the study of black holes because we do not think there are any, but it sort of anchors the sky to the things that we all know and love and that people can see either with their naked eye or with a very modest telescope or a pair of binoculars.

Roland Van Der Marel: For the study of black holes, one of the first things that is of interest is this object called binary star. So if you move the viewfinder around, you will ultimately find a binary star somewhere, which is just a pair of two stars that go around each other.

Now our sun is actually somewhat special in the universe, because half or more of all the stars are believed to live in pairs. They are two stars circling around each other. Our sun is believed to be solitary.

Now these binary stars, these pairs of stars are of great interest to astronomers because the orbits of the stars around each other are determined by gravity. Gravity allows you to measure masses of the object if you understand the forces of gravity and do detailed observations.

Binary stars have proven to be of great importance to astronomy in general, and they have also proven to be of great importance for the study of black holes.

Now, the objects listed as red giant, planetary nebula and supernova remnant, those have to do with late stages of a star’s life.

A star is an equilibrium for many billions of years because it undergoes nuclear fusion in its center that produces energy. The energy tends to push the star outward. The gravity of the star itself tends to pull it inwards and the balance of these forces produces a long term equilibrium.

At some point, the star runs out of nuclear fuel and then various things happen to it when it is in its death throes and, you know, cannot resist the attraction of its own gravity anymore.

A small star like the sun will become a red giant first. I will not have time to talk about this much. It will blow away its outer layers but it will not become a black hole. It will become a white dwarf.

A white dwarf is basically the remnant of the core of a star like the sun where the object is fairly small, but it can still withstand its own gravitational pressure, because it is not heavy enough for the gravitational attraction to be very large.

If you have a very massive star, it will explode at the end of its life in a super nova explosion, and the core of the star will be so heavy that it cannot resist its own gravity.

It will fall all the way to the center to the point where it becomes a black hole. There is an intermediate stage which is called a neutron star, where the star is too heavy to be a white dwarf, but it is not heavy enough to become a black hole.

In a Neutron Star, essentially all the protons and the electrons of the star are pushed into each other so that it becomes just a ball of neutrons, but these neutrons do not like to be pushed into each other, and therefore they sort of resist any further contraction.

If the star is massive enough, say more than 25 times the mass of the sun, the star cannot exi - the core of the star cannot remain as a neutron star, it will become a black hole.

Well, do we know that this is all true? That these black holes really exist? Well the good answer is yes, and people have got a Nobel Prize just for showing this.

If you go to find the X-ray binary on the sky, you will find an object that in optical lights just looks like a regular star. It just looks like a point on the sky like we see many. But when people started launching telescopes that detect X-ray emission in the 1960s they saw from that particular place in the sky a huge amount of X-rays.

And the X-rays are much more than we see from any normal star. And as it turned out, what is happening is that it is a pair of stars. One is a normal star which we can see in normal light with our normal telescopes.

The other is a compact object. It is a star that has died. But it is still going around the normal star, and as it's doing so, material from the normal star is actually trickling into the compact object.

And it is falling into this very dense object. And as it is falling, it gets compressed into a small volume.

And as it gets compressed into a small volume, there is all the friction. The gas heats up and as it heats up it starts emitting these X-ray waves.

We can see these X-ray photons coming towards us. We can detect them. Now the wonderful about this particular system called Cygnus X-1, is that since it is a pair of objects, you can actually look at the visible star that we can observe with regular telescopes, and you can take a spectrum of it, and you can see that the lines of the spectrum actually move back and forth with a period of a couple of days.

You can actually see that the star is going around something else, and you can use that to calculate the mass of the other object. And the mass of the other object turns out to be about ten times the mass of the sun.

And we know from physics that a white dwarf cannot be more massive than 1-1/2 times the mass of the sun more or less, and the neutron start, can never be more massive than three times the mass of the sun.

If you find a compact object that is a star that has died and you find that it is ten times as massive as the sun, the only thing we know of that it could be is a black hole.

Now, if you go to super massive black hole...

John Stoke: Actually I have a question, if you do not mind. I will interrupt here. This is John. Cygnus X-1 was sort of prototype for this and that was several decades ago right since this is found. There have not been that many of them since right? What does that tell us?

Does it tell us that the beams of X-rays are highly collimated or that this is a fairly rare phenomenon or the period of time in which the other member of the binary pair is still active is kind of limited?

Roland Van Der Marel: We have much more powerful X-ray telescopes than we had in the 1960s obviously. And we can look at other galaxies and we see these X-ray sources all over the place.

You can look at say the Andromeda galaxy or the triangular galaxy, and you can see lots of these X-ray sources that just look like little points of X-ray light, and we know pretty much that all of them are either Neutron Stars or black holes.

The only thing is that for most of them, we cannot determine whether they are either neutron star or a black hole because we cannot study the system in enough detail to determine the mass of the compact object.

And if we do not know its mass, we cannot know if it is a black hole or not. We can only know that if we can demonstrate that it is more massive than say five times the mass of the sun.

But just from statistical arguments, we know that these things have to be very common, but Cygnus X-1 is just a very fortuitous source which provides (all of) information to us, which is not really available in many other circumstances.

This is one mechanism for forming black holes that formed from stars, and therefore have typical masses similar to stars.

But there is a second class of black hole which is the super massive black hole, which is a black hole that is about a million to a billion times as massive as our sun.

These black holes exist in the centers of many galaxies, including the center of our own Milky Way galaxy.

We know that in the center of our Milky Way galaxy, there is a black hole that is 3 million times as massive as our sun. We know that the Andromeda galaxy has a black hole that is about 30 million times as massive as our sun.

How did we learn about the existence of these black holes? Well again we learned by combining the information obtained from observations at different wave lengths.

If you move your viewfinder around enough, you will find an elliptical galaxy, sort of top left of the screen and that in optical light, in visible light, looks like a blob of light which is just the some of the individual billions of stars that exist in that galaxy.

But if you look in radio waves, you will see that the thing looks very different. The galaxy has a bright point in the middle and then there are these two lobes of gas coming out on the left and on the right.

The amount of energy associated with these lobes that you see in radio emission is enormous. And astronomers have calculated how much energy is involved and what could potentially produce that. And the only thing that they could think of at the time was that there was a black hole in the very center of the galaxy.

And the reason that that is a plausible explanation is that a black hole can turn mass into energy very efficiently. It is a very efficient energy machine provided that you have something available to put in it.

Now this was a paradigm already quite a while ago, but this had to be proven. And one way in which this was proven beyond pretty much everyone's reasonable doubt is that astronomers were able, in several galaxies including our own Milky Way, to actually measure the velocities of stars or gas very close to the center of the galaxy.

And they could demonstrate that the velocities were so high, and for example Hubble Space Telescope was of great importance in this particular field of research. The velocities near the centers of many of these galaxies was so high that it had to mean that something very dark and very massive was pulling on the material because it is the gravitational pull that produces these high velocities.

This first module provides insight into how astronomers have learned about black holes and how we are still learning about black holes.

If you go to page 6 of the PowerPoint presentation, or in the Web site you click on The Voyage, you get into the second module of the Web site which actually allows you to travel to a black hole, either the Cygnus X-1 binary star where you see, you know, a dark object drawing matter or rather material is falling off the companion star around it, or you can go to this super massive black hole in the center of Andromeda, which is of course our nearest big neighbor galaxy in space.

This is something that you will probably have to pursue at your leisure later. This will take a few minutes to go through this. But if you click on one of these two, you can sort of see what it looks like.

You get the view of a cockpit. You look out of the cockpit and you see initially the Earth with the moon on top of it. You can choose a velocity and then you can start your travel through the universe to this black hole that you have chosen.

And what this is intended to do is to show people something about the scale and size of the universe. The enormous distances involved and the enormous speeds that you need to achieve to get anywhere in the universe.

Your travels take you through the Solar System. It will show you the planets and the like. It will take you then through our own Milky Way galaxy if you want to go through the Cygnus X-1 source, or if you want to go to Andromeda, it will take you out of our own galaxy, and it will show you what is involved and your cockpit will show on the right the time you have traveled, and measure the distance you have traveled in light years, and on the left, the speed that you have attained.

The nice thing to note there is that your speed is measured in percentage of the speed of light, and you can get as close to the speed of light as you want. If you have a hypothetical spacecraft that can produce more and more energy whenever you ask it, you can always get closer to the speed of light, but you can never get to the speed of light.

This is again one of the predictions of the Theory of General Relativity that you cannot move faster than that, no matter how much energy you put in your machine.

Now the seventh slide of the presentation shows you some screen shots from when you get close to the Cygnus X-1 source. If you want to see it on the Web site you will have to do the travel, so I suggest you do not at this point. Maybe pursue that later.

What you are seeing is you are seeing the compact object. You see a disk of gas around it. This is gas that is falling from the other star and circling around the black hole.

Because it is gas, it has internal friction. And that friction leads to heat that leads to emission of energy, X-rays in this case, and at least a loss of energy. And loss of energy means that stuff will fall to the center and will ultimately end up in the black hole.

What you also see is you see a jet of material coming out perpendicular to the disk. These jets we know exist because we can see them when we take images in radio waves or in X-ray emission of many galaxies around us, and also in these binary sources of stellar mass objects.

They are produced by magnetic fields associated with the disk. Particles are accelerated at high speeds away from the black hole due to the magnetic fields and they radiate as they move away energy that we can observe.

Now an important thing to note here is something that is sort of counterintuitive. That is, I have told you that you cannot see anything that is in a black hole because it can never get out.

On the other end I have showed you that we can find black holes and we can see them and identify them, and you may think well how can we see them if nothing can never get out.

Well the answer here that is indeed we cannot see what is inside the black hole. However we can see the stuff that is near a black hole. And the stuff that is near a black hole will behave very differently than the stuff that is in more typical parts of the universe.

The stuff that is near a black hole will behave differently because it is feeling much higher gravity. It feels much stronger forces, and therefore it leads to phenomena that we can observe that we do not see elsewhere in the universe.

All of our evidence for these black holes comes from the stuff outside of black holes not from inside the black hole itself. We can never see what is inside a black hole, because whatever is inside a black hole, can never emit light that comes out.

Going to page 8 of the presentation, and for those of you looking at the Web site, click on Up Close and Personal. This starts with a little animation that I do not really want to say too much about because it is kind of complicated. You can read it at your leisure.

I suggest you click Show Questions and Experiments on the Web site and that will show a bunch of questions on the left and a bunch of experiments on the right.

And these questions are questions that are often asked about black holes, or that, you know, one might want to know the answer to. So you can click here and find answers, pictures, explanations of these things.

Let me quickly go through some of the questions. What is a black hole? I think I have explained that already.

Do black holes obey the laws of gravity? Well definitely they do. In fact, gravity is what defines a black hole to be a black hole.

The first question that gets sort of a little deeper and complex is how big is a black hole? The answer there is kind of interesting because all the material that makes up a black hole is condensed into one point. There is no size to it. The size is zero.

It is called a singularity. All of nothing can stop the material in a black hole from falling to the center and therefore it falls all to exactly the same point. Nothing can withstand the gravitational attraction that wants to attract it to the smallest size possible.

Nonetheless, there is sort of a characteristic size that you can associate with a black hole which is the distance away from the center that you can get while still being able to escape.

You can imagine a point of infinite density and high mass, a black hole, and surrounding that, think of a hypothetical sphere. And the size of that sphere is such that if you are outside of that sphere you can still get away from the black hole provided you have a spacecraft with enough energy.

When you are inside that sphere, you can never get away anymore. No matter how much energy your spaceship has, you will never get away anymore.

That sphere is called the Event Horizon. If you are inside the Event Horizon, you are doomed. If you are outside the Event Horizon, you can still get away.

The fourth question is what is inside a black hole? Well this is again interesting. And you may think well haven't you just answered that. There is pretty much nothing and all the material is in the center.

Well, yes and no. The theory of general relativity predicts that all the material of a black hole is in a single point in the center. On the other hand, whenever a theory of the world predicts that something is infinity, like the density, you have to wonder whether maybe you have missed something, because usually in the universe things do not like to be infinity.

And it is the same here. You actually get to a point where the material in the black hole is in such a small volume that gravity is not the only important force anymore. You get to a point where quantum forces become important.

Those are the forces that dominate the behavior of material on the smallest scales in the world. So you get to a point where you need a new theory, which is called Quantum Gravity.

Now, the nice thing about this theory is it has a name. People have studied it for 50 years, but unfortunately no one really knows what the theory really is, how it works and or has been able to observationally verify it.

Einstein in the last 20 years of his life had as his main goal to sort of try and outline what this theory was, and he did not succeed. And he died in 1955. We are now 53 years further and even though we have learned a lot, we still have no definitive theory.

There are good candidates like Super Strength Theory which you may of heard of. There are other theories. One of the big problems is that having a theory is one thing, proving that the universe actually behaves that way is much different, because it requires you can actually probe very high energies and very small scales where these theories would have an effect, and we really cannot.

However, inside a black hole you get to a point where you need this Quantum Gravity to properly describe what is going on. And we do not really know. And this does mean that there is a level of uncertainty about what is inside a black hole that we cannot resolve.

That also means that there remains room for outlandish theories and wild speculations as well as creative and important science.

When you hear about a black hole, you should think these are objects that have been demonstrated to exist that people study all the time.

When you hear about Worm Hole or White Hole or Time Travel or any of these things, I can tell you serious scientists have written serious papers about these things. On the other hand, whether any of them have anything to do with the real universe remains to be demonstrated. Okay?

It is really a different type of subject you are talking about then. On the other hand, people often like to ask about these things because they have read about them or they have heard about them or they are just fascinated by the idea of not knowing what is out there, or the idea of being able to travel back in time for example.

Next question, what types of black holes are there? Well again there is an interesting answer there which is that if you look at people, there are many types of people. We are different in, you know, an infinity of characteristics - our eye color, our hair color, our, you know, whether it is curly or whether we are bald, or you know, there is plenty of things in which we differ.

Black holes are very simple. A black hole has only three properties period. It does not matter whether the black hole forms from planets, bricks, houses, cruise ships, stars, galaxies. Once it is a black hole, it has only three properties - mass, spin and charge.

Charge, we actually believe is completely unimportant for black holes because say you had a black hole that had an electric charge that was positive, then it would electro-statically attract electrons, and the electrons would fall into the black hole and neutralize it.

That is pretty much the same for other objects in the universe like our Earth. We do not actually believe black holes have charge, even though in principle they could have, which leaves only two real properties - mass and spin.

The fact that black holes have so few properties is referred to the no hair theorem. Again this dates back to John Wheeler, the issue being here that black holes are not like people. They do not have hair that we can use to discriminate them. They have no hair.

Now, masses of black holes we understand pretty well and we can determine, and I have told you that we have this super massive black hole and the black holes that are about as massive as a star. The spin of black hole determine whether the black hole sort of spins around an axis.

That is much harder to measure, but that is actually something we are making progress on. We do think many black holes do spin because many black holes have these jets associated with them, and these jets indicate that there is some excess of symmetry, and the only parameter that a black hole that would produce this excess of symmetry is its spin.

We do think that with X-ray telescopes of the next 10, 20 years, maybe we will be able to figure out also the spins of black holes, and that means we have a pretty good handle on all the measurable properties of black holes in the universe.

And interestingly, that makes them at some level the best understood objects in the universe because pretty much everything else that is out there, there is lots of details we do not know. The devil is always in the details.

The nice thing about black holes are, they do not have to have many details. They simply can't.

Next question, what happens when black holes collide? Well that is another intense area of research because what happens is black holes have a large amount of gravity. And Einstein's Theory of General Relativity showed that gravity is really nothing else than curvature of space time.

Space and time are tied together into a four dimensional manifold curved. And the curvature is due to the mass and the gravity that is there, or rather due to the masses there and the curvature of course responds to the gravity.

If you have a black hole, which is a very highly gravitating object, and it runs into another black hole, which is another highly gravitating object, and they merge, you get ripples that go through the space time of the universe. And these are called Gravitational Waves.

They were predicted by Einstein. They have been detected sort of indirectly. So no one has ever detected a Gravitational Wave, but people have shown that there are binary systems that are losing energy consistent with the predictions of Gravitational Wave Theory even though we cannot actually detect the waves themselves.

But a highly active area of research is to try and detect these gravitational waves. There are experiments in the U.S., LIGO with two sites at different locations that are trying to detect this.

There are other experiments in Europe and elsewhere. And there are plans for an gravitational wave observatory in space called LISA. All of those, when successful could not only provide real breakthrough and actually, you know, finding detecting these waves, proving they exist, proving Einstein was wrong, but they will also provide a whole new handle on black holes and their properties, and, you know, where they are in the universe, how they formed and all of those things.

Next question, how many black holes are there? Well I can assure you, plenty. It is like asking how many grains of sand are there on the beach. We think that about one out of every thousand stars roughly is more massive than 25 times the mass of the sun. And that is based on real observations because very massive stars are very bright and we can observe them really well in our own galaxy and elsewhere.

Those stars become black holes in, you know, millions of years. So if we just integrate this over the lifetime of our Milky Way, we believe that there should be about 100 million black holes in our galaxy alone, and our galaxy is very typical.

There is also this super massive black hole in the center and the visible portion of the universe has billions and billions of galaxies in it.

We are talking about billions multiplied by billions, so even though the number of black holes that we can point at, identify and characterize, maybe is not that large, because you usually need special circumstances to be able to study them well, the number that is actually present in the universe is enormous.

They are not sort of freak accidents of nature and there is a few of them out there. There is literally billions and billions of them.

Next question, how are black holes born? I have discussed that quite a bit already in terms of the evolution of stars so I will not say more.

How do black holes grow? Again, they grow by essentially like Venus flytraps. Material that is close to it and is heading towards it tends to fall into it. Material that is close to it that is radiating energy is losing its energy and that loss of energy causes it to fall.

Think of an airplane that is undergoing friction. It slows down. It loses energy. Ultimately it will fall back to the Earth. Same thing happens to something close to a black hole.

Man: I have a question. If nothing happens to be falling in to a particular black hole at a particular time, that means that it is going to be not detectable by us, is that correct?

Roland Van Der Marel: Correct. If nothing falls into a black hole, it is not emitting any radiation. It will look perfectly black to us. We will have no idea it is out there. And in fact, most black holes in the universe are exactly in that mode.

It is primarily the ones that are in a binary system where they are lucky enough to have a very massive star nearby that is slowly losing material, or this black holes that are in the centers of galaxies where all of the material is often available that are in a position where they can grow significantly.

And that growth usually goes associated with transfer of mass into energy, and part of that energy escapes before the material enters through the Event Horizon and we can observe it.

Final question, do black holes live forever? Well that is another good one. You would think that if stuff can only fall in and never come out, it has to live forever because you could not really destroy it could you?

Well the answer is no. That is not true. Stephen Hawking had this remarkable finding a few decades ago where he shows that you can be in a situation where out of the vacuum near the Event Horizon you can spontaneously create two particles - a particle and an anti-particle.

And that is actually not so special. That happens all the time, you know, every vacuum, physicists know. But you can be in a situation where one particle just gets out of the Event Horizon before the particles can annihilate together and merge again with the vacuum.

One of the particles might actually escape and the other fall back into the black hole with the probability that is not quite zero. You actually end up with some radiation leaking out of the black hole.

Now this radiation is called Hawking radiation. It is very little. For the black holes that we know in the universe, it is completely irrelevant. It does nothing. It is completely unobservable. The black holes will exist for ten to the hundred years before they will disappear due to this leaking of radiation.

But in principle, for smaller black holes, this would actually have an effect. A black hole sort of the size of a big building would actually disappear in about of a second due to this spontaneous evaporation process.

The nice thing about this finding is that it has to do with black holes and Quantum Theory. So you may remember what I said before that this process, this Hawking process actually bear some relevance to quantum gravity.

Again, it is sort of the one of the things that is best understood as a limiting case of quantum gravity that has actually been studied, but as mentioned before, many mysteries remain.

The final part of the Web site, and on the right side of page 8 of the presentation and still on the same page of the Web site, there are five experiments listed.

Experiment meaning here you can go in and you can get some interactive applets or application or flash module that allows you to see what is going on and sort of do an “experiment”.

You can create a black hole by choosing the size of a star and seeing what happens to it at the end of its lifetime.

You can orbit around the black hole which shows that you can actually move around the black hole without necessarily falling into it. That shows that black holes are not vacuum cleaners.

You can find the mass of a black hole. That is an experiment where you have a black hole and a normal star moving around each other, and in a binary system, and you can use the speed of the motion to determine the mass of the black hole.

You can drop a clock into a black hole. And that is shown on page 9 of the presentation which is the last page, or it is shown by actually clicking on that particular experiment in the Web site.

That shows a situation where you are on board a spaceship and you have two clocks. One of the clocks is onboard your spaceship and you keep it there, and the other one you are dropping into the black hole that you are circling around.

If you do that, you will find that strange things happen. The clock that falls into the black hole never actually seems to get there. It seems to sort of freeze when it reaches the Event Horizon and time appears to stand still on the clock.

All of this has to do with the Theory of Relativity which in its essence shows that things are relative. What is the time for the person on the spaceship is not the time for the person or for the clock that is falling into the black hole.

For the person on the spaceship, the clock will never actually enter the black hole. And the reason for that is simple, because we could never see it enter because once it is entered its light cannot get out anymore.

The clock that is falling into the black hole, on the other hand, notices nothing. The Event Horizon is a purely hypothetical surface. There is nothing there.

The clock will simply fall into the black hole in a finite amount of time. It will hit the central singularity and merge with that and it will be over. Reality will be quite different for the clock falling into the black hole than for the clock that is on the spaceship and they will run out of sync.

For one of the two, time will appear to stand still, for the other time will keep running in its normal way.

It would take me a little more time to explain all of this in detail, but you may all have heard about the twin paradox in general relativity which is related to something very similar.

You could have two twins, one of them stays behind, the other goes on a space trip, accelerates then returns and then when the other twin returns, the first twin has aged much more than the other twin.

Again, this relates back to the same properties of the theory of relativity that time and space are intertwined in a way that is very (momentous) to us humans.

Then the final experiment is that you can actually drop into the black hole yourself. And when you do that, you will find that your body gets stretched apart significantly, and that is because of tidal forces. It is the same forces that produce the tides on the Earth.

In this particular case, what happens is that your feet are closer to the black hole than your head, therefore they feel a higher gravitational pull than your head, which leads to your body being stretched apart.

If you fall into a stellar mass black hole, your body will be torn apart long before you get to the Event Horizon. If you fall into a super massive black hole, counter intuitively even though the black hole is much more massive, the tidal forces are much lower at the Event Horizon and you will be able to enter the Event Horizon without anything happening to your body.

You would be able to notice it, to write about it in your memoirs. The only problem is you would not be able to communicate back to the people on your home planet that sent you there because your communications will never get out of the Event Horizon.

What I try to convey with all of this is sort of the fascination of black holes, some of the things that touch on the current research and the current interest of physicists and astronomers. We will also highlight a lot of key things that you can all bring back to the people that you talk to in your Outreach activities and your other work activities, or even when you just sit in the airplane and someone asks you, you know, about astronomy, you can tell them about some of these things.

People tend to be fascinated about it. And they often tend to be fascinated about the fact that we can actually understand a lot of these things. And that is maybe the most important message to take away from all this.

That is as much as I wanted to say here. Let me open the discussion to anyone who may have questions, if any and see what we get.

Earle Kyle: Earle Kyle, Solar System Ambassador, NASA Solar System Ambassador, Rochester, Minnesota. When you were talking about the colliding black holes, you said nobody has detected the ripple, the gravity ripple.

Roland Van Der Marel: Right.

Earle Kyle: And that if somebody did, then it would prove Einstein wrong?

Roland Van Der Marel: No. That would prove Einstein right in the sense it would be consistent with what Einstein predicted.

Of course, it is hard to validate all aspects of a theory because there is an infinite number of experiments in principle you could do. But Einstein's theory definitely predicts these gravitational waves, so we definitely would like to observe them.

The problem is they are very weak. What you need to do is if a gravity wave passes by the Earth, then say I have two wakes. I have a bowl and, you know, sort of bowl of metal on the left on the table and a bowl of metal on the right on the table.

Then when the gravity wave passes, the distance between the bowls changes slightly, and you would like to measure that. The problem is that the change in distance is about, you know, it is smaller than the size of an atom, so it is a very difficult measurement.

You need to set up very smart experiments over large distances with lasers and stability against seismic events on the Earth that also cause vibrations and distance changes, and it gets to be very difficult.

Now the one piece of indirect evidence we do have for this gravity waves is that there is a system of pulsars. It is a binary pulsar. A pulsar is a neutron star. A pulsar is a spinning neutron star whereby a radio beam emanates from the spin axis that we can detect on Earth and this causes sort of like flashing, pulsing.

Now these pulsars usually are found by themselves, but there is this unique source where there is two pulsars that are going around each other, and we can get pulses from both of them.

By monitoring that system, we see that their orbital period changes, and this is due to loss of energy. And this loss of energy, we can calculate how much energy we would expect this system to lose because of inertia gravity waves.

This is exactly the same as the change in the period between the pulses that we observed. And this is something that two people got the Nobel Prize for some 20 years ago or so.

But this is sort of the best evidence we have for the existence of gravity waves, but it is not quite the same as actually directly detecting them.

Other questions?

Man: I have another question which is that as you certainly know, the Hubble Servicing Mission is coming up. We have other observatories with another missions coming in the future in the NASA world and other ground base facilities. Do you have a sense for how any of those will advance the study of black holes?

Roland Van Der Marel: Yes I think one of the, one of the things that have come out of many years of research with the Hubble s pace telescope is that black holes exist in most galaxies in the universe, and we can sort of weigh them in nearby galaxies.

But we do not really understand that how these black holes in the center of the galaxies grow and get to be as massive as they are. It is sort of an embarrassment.

The black holes that have the masses of stars we understand pretty well from basic theory. The black holes in the center of the galaxies, we can demonstrate they are there. We can sort of make some models for how they may have gotten there, but it is not really a very clean prediction.

There are many different ways they could have grown. We would like to grow quite generally how to galaxies grow as the universe ages. And it seems that these black holes grow together with the galaxies they fit in.

There is something associated with the process of galaxy formation that causes a small fraction of all the material in the galaxy to end up in the center in a black hole.

I think with upcoming observatories and observations, people are starting to look into that more and more, getting a better handle on sort of the common growth of black holes and galaxies in the universe. And is it one that drives the other? Is it just sort of that the black hole is sort of the trash can of the galaxy that everything that did not end up in a star sort of falls to the center and basically grows into this big black hole.

It is that type of question astronomers would really like to get an answer to in the next decade or so.

All right, any other questions out there?

I would like to encourage anyone who would like to make use of that kiosk version to just click - if you go to the Hubble source web site reference that Roland gave in the PowerPoint and go there, you can click and enter your, you know, your name and institutional affiliation and we will get that out to you.

We do not just have it posted for immediate download just because as you know in the NASA world, the credit is the coin of the realm and it is helpful for us to be able to report back just as the case with Anita's operation. She is making use of the resources that we created.

If there are not any other further questions, I would like to thank you very much. I am not sure exactly what we will have...

Man: Excuse me, is this PowerPoint presentation and this talk somewhere we can pick up off the Web site, you know, at the Ambassadors site or something where we can get these at a later date?

John Stoke: Yes they all get archived.

Anita Sohus: It will be posted on an Ambassador site probably this weekend, and it is also on the Museum Alliance guest site.

Roland Van Der Marel: Yes let me just repeat that the main Web site that I was talking about which contains intimately more information than the presentation, the main Web site you get to by going to hubblesite.org/go/blackholes. No capitals, no spaces, no dashes, so hubblesite.org/go/blackholes.

Man: This Web site, is it legal to show it in the planetarium for our astronomy club or is it strictly just to members?

Roland Van Der Marel: It is free on the Web. Anyone can do whatever they want with it. The kiosk site is a little different in the sense that it is not just out there on the Web. You need to ask us and we can send you the software so you can install it on your computer.

That is something we could certainly discuss but probably would do offline with you.

But the Web site, the Web site itself which is out there on the Internet just like everything else and you can do with it whatever you want.

John Stoke: It is also the kiosk version is free by the way. There are no royalties associated.

Anita Sohus: And of course we always like feedback on how you use it.

Paul Cirillo: This is Paul, an Ambassador in New Jersey. I just wanted to compliment everybody about this because this site is absolutely fantastic. I was looking at the credits. You have already gotten some awards.

Let me just add the Puller award from New Jersey. It is fantastic. A lot of my students ask about these things and in one great place you have all the answers including hands on. My hat's off to you. Enormous compliments. Thank you.

John Stoke: Thank you so much. I appreciate it. And I will let my other collaborators know as well.

Paul Cirillo: Thank you. You are very welcome.

Anita Sohus: If we have no other questions, I will repeat the Web site for the PowerPoint. It is http://informal.jpl.nasa.gov/Guest. The user name is informal. The password is lifelong.

And the materials should be posted on the Solar System Ambassador site this weekend when our Webmaster is in.

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