NWX-NASA-JPL-AUDIO-CORE

Moderator: Ms Anita Sohus
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2:30 pm CT

Anita Sohus: Great. Thank you. And welcome everybody to the Hubble Space Telescope Science Briefing for June. I apologize for some confusion because the dates had to change and evidently there were some people who dialed in at 12:00 o'clock instead of 12:30. So I apologize for the confusion when we have to push things around.

And Kay was just telling you about muting your phones and don't put them on hold. Star 6 will mute your phone if you have to have a conversation or typing. Star 6 again will toggle and let you speak if you wish to ask a question.

So with that I would like to introduce our speaker today. Doctor Jason Kalirai is an astronomer at the Space Telescope Science Institute and he specializes in stellar remnants that are called white dwarf stars. So with its new capabilities and fresh (unintelligible) abilities, it is also going to be able to look at (unintelligible) again and more. So I am going to turn it over to Jason.

Carolyn Slivinski: Okay. Let me introduce myself first. This is Carolyn Slivinski from Space Telescope Science Institute. I am filling in for the part that Frank Summers normally plays during these telecons. He is at the AAS meeting.

I will be stopping the presentation now and then to give the listeners a chance to ask questions, but feel free to interrupt us if you have a question. Today we have Doctor Jason Kalirai. He is an astronomer at Space Telescope who studies the formation and evolution of stars and galaxies in the local universe.

His current research interests involve imaging and spectroscopic observations of resolved stellar population, I dare you to say that five times fast, such as nearby star clusters and dwarf galaxies.

Jason is also very active with outreach activities. So he should be able to identify with you all in museums. So I want to make sure you are on slide number 1, and I will turn this over to Jason.

Jason Kalirai: Okay. So thank you very much everybody. Good afternoon. So as Carolyn mentioned, I am a new astronomer here. I just showed up in the fall and I am carrying out some interesting research programs on better understanding stellar evolution and I will share some of those with you guys today.

So there is a quick outline on the first slide. So let us just go through this very quickly. So I want to start by presenting a brief introduction and really a historic look at how astronomers had their first hints on the way that stars evolve and what properties, what parameters of stars may dictate that evolution.

I will very quickly summarize our current picture of stellar evolution and then go back and discuss what was really one of the first important discoveries on remnant stars. It was a surprise on our backyard and ended up being the first discovered white dwarf star in the mid 1800s.

I will provide some justification for why we actually want to search for these white dwarf stars which are in a sense dead stars. I will describe what they are in a few slides.

And then I will go on and talk about a huge program that we have undertaken with the Hubble Space Telescope. Several times now we have already completed sort of two phases of the program, and the third phase will be completing in the fall of this year with the refurbished Hubble Space Telescope.

And I will describe some imaging observations that have led us to construct some of the deepest images ever obtained in astronomy, and I will talk about some of the science that comes out of those observations.

And then I will conclude by presenting a summary as well as some discussion about what the future outlook is of this type of field. So we can go to the next slide please.

Okay. So a very interesting correlation was discovered by a Danish astronomer named Hertzsprung in the early 1900s. Hertzsprung was looking at the night sky and he noticed that if you look at stars they vary in brightness.

Now stars can either vary in brightness because they are intrinsic brightnesses are different or because their distances are different, that is a star that is further away will appear fainter to our eyes.

At the time there were very few proxies for actually determining what the distances to different stars were. One of the popular techniques involved parallax measurements. So parallax is a simple measurement, and there is a diagram on the right hand side to illustrate it.

So if we look at the earth when it is on the left hand side of the sun, say we call that January, and then we look at some star in the middle of the picture, we see behind that star there are more distant stars that make a certain pattern in the sky.

If we now wait six months till the earth comes around to the left and ends up in July on the right hand side of the diagram and we look at that same nearby star, the pattern of stars behind that star has changed.

And the reason that’s changed is because of parallax because of sort of the prospective motion that our eyes perceived for that star. So the – in reality, this diagram is highly exaggerated because the distance between the earth and the sun is tiny relative to the distance to the stars. The stars are very, very far away.

So if you look at this diagram, you can actually make a neat little triangle with it. And there is an arrow, a double sided arrow marking the parallax angle on the diagram.

And that parallax angle is simply related to the distance between the earth and the sun and the distance between the earth and that star. So it just forms a nice little triangle.

So the parallax angle ends up being the ratio of the distance to the earth to the sun which we call one astronomical unit. It is about 150 million kilometers in real distance. So it is that distance divided by the distance to the star.

So what Hertzsprung noticed was when he looked at nearby stars that had the same parallax, right, they had the same angle. That implied that they were roughly the same distance. But he noticed that those stars still had different luminosities.

So how could it be that there were a set of stars that were the same distance away from the sun but they had different luminosities. And he coined a term that still sticks strong in our minds today as astronomers. He referred to the bright stars as giants and he referred to the faint stars as dwarfs. And that is where that nomenclature comes from, Hertzsprung having created the first luminosity classes for stars.

Hertzsprung also noticed that in addition to this general sort of dichotomy between giant stars and dwarf stars or say bright stars and base stars, that there appeared to be a correlation between the luminosities of the stars and their colors. So that is the bulk of stars had this correlation where as the stars' colors were bluer, the stars happened to be brighter.

So if you go to the next slide please, we can see a diagram that is probably one of the most influential diagrams in astrophysics, not just stellar astrophysics but astrophysics. And it is a diagram that is named after Hertzsprung and also after Henry Norris Russell who was at Princeton at the time.

So it is a simple, very simple diagram that plots the luminosity of stars on the Y axis, and so stars that are at the top of the diagram are very bright and stars that are at the bottom of the diagram are very faint. And on the X axis it plots the temperature where things that are sort of an inverted scale of temperature, so things that are hot or have a higher temperature on the left and things that are cool have a temp – are on the right hand side.

So if you look at this diagram, you see that there is clearly a swath of stars that forms a diagonal band extending from the bottom right to the top left. And the luminosity range is truly spectacular. And this is actually a logarithmic scale so that – the brightest stars that you see on this diagram are about a million times brighter than the faintest stars on this diagram. So the dynamic range is huge on this diagram.

But then you see these exceptions, right? At the same temperature, you see both bright stars and you see both faint stars. And those are the giants and the dwarfs that Hertzsprung referred to in 1905.

So if you click the next slide, you can actually see some of the original papers and Hertzsprung and Russell wrote. And unfortunately astronomers have been very lazy in referencing these initial pioneering fundamental papers. So these, you know, three four papers, fundamental papers have a combined, you know, four five citations between them which is unfortunate.

But you can see the intuition that Hertzsprung and Russell had. So some of the quotes about halfway down on the slide, you know, Henry Norris Russell in 1913 remarks that, you know, one corner of the diagram is vacant, that there does not seem to be any faint white stars. All of the very faint stars are very red.

And then he said the converse propositions are not true. There is no doubt at all that there is this many very bright red stars. And these are the same bright red stars that we can see with the naked eye such as Arcturus, Aldebaran, Antares. And then Russell actually remarks that there appears from the rather scanty evidence at present available to the sum correlation between mass and luminosity which is something that is a fundamental property of stars that we understand well today.

But Russell had the intuition to really sort of come to this conclusion based on these very, what we would consider today very ratty data.

Now if we just actually go back one slide for a second, if we hit the back arrow key, you can see that, you know, on this first Hertzsprung Russell diagram there is in fact one faint blue dot, right? If you look closely at the faint, sort of the bottom left hand, there is one star there.

And that was actually a star that Henry Norris Russell questioned. He questioned the measurements of this star and suggested that because it is such a big outlier from the rest of the sequence that perhaps there is something wrong. Perhaps we have measured its luminosity incorrectly or its temperature incorrectly.

In reality, that one faint blue star is the first known white dwarf star in the galaxy. And it is a very interesting system. It is actually one star in a triple system that is located about 15 light years from the sun.

So it is a very close star and it is also a very popular system in a popular culture. This is actually – the name of the primary star is 40 Eri A. And that is actually the star that the Vulcans were from in Star Trek. They were from 40 Eri A, okay?

So we can skip ahead two slides now, so we get passed the…

Carolyn Slivinski: Okay so we are going to slide number 4.

Jason Kalirai: Okay. So on slide number 4, you can see sort of an artist depiction of stellar – of the Hertzsprung Russell diagram and stellar evolution that you – you can see that there is a broad swath of stars called the main sequence in the middle of the diagram.

The main sequence represents stars that are burning hydrogen in their cores, infusing that hydrogen into helium. And a star will actually spend about 90% of its life in this state on the main sequence. After the star finishes exhausting that hydrogen in its core, it actually begins to burn hydrogen in a shell around the core. And when that happens its luminosity increases. And those are the giants that you see in the top right part of the diagram.

And the star really zips through these other phases pretty quickly. It will only spend a small amount of its time as a giant. And then once it has exhausted all of that hydrogen, even in the shell and it has burnt away any helium that it might have, it will actually fade and cool into the sort of faint blue or the bottom left part of this diagram and become a white dwarf.

So the two key properties that I want you guys to take away from this diagram are one that star formation and the processes that lead to the formation of stars have a bias in that they produce predominantly low mass stars. And that is actually depicted on this diagram. You can see that the faint red part, the lower right corner of the diagram has all of these very small low mass stars, and whereas at the upper left hand side, there are very few bright stars, more massive stars.

So these are, you know, this is a property of star formation many more low mass stars are produced than high mass stars. And then the second key property is that stellar evolution depends primarily on the mass, right? I mean the stars have many properties.

They have rotation rates, they have magnetic fields, they have metalicities, but all of those properties are secondary to the mass. And the way that stellar evolution depends on mass is interesting as well.

If you have a more massive star that more massive star is like a sports car. It guzzles through all of its gasoline, all of its hydrogen supply in a very short amount of time, does its thing, becomes a giant and goes on to other fates, whereas a low mass star, some of those objects that you see in the bottom right hand part of the diagram, those stars will actually burn hydrogen very, very efficiently.

They are like your Honda Civics or your Prius, nowadays I guess. They take, you know, sometimes some of these stars will take longer than the age of the universe to exhaust their hydrogen supply. So that star will stay on the main sequence for billions and billions of years.

Okay. So if we go to the next slide, slide number 5, we can see sort of a depiction of how the mass of the star relates to the eventual end fate of a star will be. So at the top of this diagram you can see very massive stars. And those massive stars after they exhaust their hydrogen, the envelope of the star will actually collapse and bounce off the core, and this is something that we call a super nova explosion.

So these very massive stars lose all of their mass in – most of their mass in a very explosive event and shed that material into the interstellar medium and the end fate of that is that the core will actually collapse in these stars and form an object that has such a high gravity and density that even light will not be able to escape the service of that star. So even photons cannot escape and that is something that we call a black hole.

In the middle of the diagram, you can see that, you know, less mass of stars will evolve to also form giants and they will end up forming neutron stars. Neutron stars and very interesting objects in astronomy. These are objects that are the size of the – the mass of the sun.

So they have, you know, the mass of the sun but they have that mass tied up in a very small star. So the actual, you know, sort of size - -the radius of a neutron star is about 10 kilometers, you know, the size of Baltimore City or something.

But within that small volume, there is a lot and lot of mass so it is a highly dense object.

And then most stars – remember most stars and low mass stars. Stars like the sun, most stars will actually suffer a very peaceful death. They will lose their mass in quiescent process through winds. So those outer layers of stars like the sun and these red dwarfs will slowly shed away over a somewhat longer time scale and eventually form what we call a white dwarf star which is just that remaining core that used to house – was the nuclear furnace of the star and had all of the hydrogen reactions.

So if we go to the next slide.

Carolyn Slivinski: Well tell you what Jason. I think this would be a good time…

Jason Kalirai: Sure.

Carolyn Slivinski: …to see if there is any questions about the Hertzsprung Russell since it is such a foundation of astronomy. Any questions out there?

Jason Kalirai: Anybody…

Carolyn Slivinski: All right then. We will move onto slide – we will move onto slide 6.

Jason Kalirai: Okay. So what slide 6 shows is a picture of the night sky that probably all of you have seen. Everybody has looked out at the sky and seen this on the left hand side.

So the constellation that you see in the center of course is Orion, the yellow star is Beetlejuice. You can see the three stars in the middle that form the belt of Orion.

So the brightest star on this image, and in fact the brightest star in the entire night sky is Sirius. So Sirius is the white star that is on the bottom of the image there.

And it is a very bright star. It is one of the nearest stars to the sun. So very early on in the 1840s, it was actually – so this was before Russell's diagram, before Hertzsprung and Russell thought of their diagram.

In 1840 it was known that the motion of Sirius is irregular on the sky. So if you look at how the apparent motion of Sirius as the earth goes around the sun over time does not obey a straight line like most other stars, but rather it shows a little wobble.

So the diagram on the right hand side shows what – so the blue curve that you see on the right hand side is the path that Sirius 8 took in the sky over a baseline of about, you know, 60 years.

And because of this wobble, it was inferred that Sirius must actually have a small companion star. And the motion that we are seeing is the motion of Sirius around the actual center of mass of two stars. But we just cannot see that faint star because it is so faint.

So this was predicted by Bessel in the 1840s and it wasn't until another 20 years later that that actual secondary star was detected by Alvan Clark in 1862.

So if you go to the next slide, we can actually see a picture of Sirius A which is the bright star on the top right and Sirius B which is that little dimple that you see just underneath that bright star. So that is the companion star that was predicted many years ago.

So once you resolve the two stars, Sirius A and B, you can actually figure out what the period of the orbit is, that is how long does it take these two stars to orbit around one another. And that orbit is about 50 years.

And from that orbit you can use simple gravity calculations to tell you what the mass is of that secondary star. And at the time it was expected that the secondary star would be one of these faint red stars that we just finished talking about that take a long time burning away their hydrogen because those are the predominant stars that the universe makes. The universe makes many more low mass stars.

And it was surprising that the period of the orbit suggested that the companion star had the mass of the sun because if the companion star had the mass of the sun we should see it. It should be very bright.

But in fact the luminosity of the star is only about 1/300th the luminosity of the sun. So it is about 300 times less than the luminosity of the sun but it has the same mass.

So the first order, if you look at the colors of these two stars, they are about the same. They are about, you know, sort of hot stars. And there is a simple relation in astronomy that relates the luminosity of stars to their radius if their temperatures are the same.

And that relation is such that if you double the radius of the star the luminosity changes by a factor of four, okay? So if you made the loop – the radius four times as large, the luminosity would change by a factor of 16.

And the radius – so if Sirius A and B have luminosity differences, it ends up that Sirius A is brighter than the sun. So although Sirius B is 300 times less luminous than the sun, that means it is 10,000 times less luminous than Sirius A.

So these two stars have the same temperature, but their luminosities vary by a factor of 10,000. That implies that their radii are different by a factor of 100. So Sirius B is about 100 times smaller than Sirius A despite having almost the same mass.

This picture was confirmed in the early 1900s. A spectrum was obtained for Sirius B for the companion star. And it was in fact demonstrated that this is a hot star. It is not one of these cool low mass stars.

And so this is what a white dwarf is right? I mean a white dwarf is a very dense remnant of a previous hydrogen burning star. So if you just compare these two stars, the parameters of these two stars, if Sirius B is 100 smaller than Sirius A, that means that its density is about a million times more dense, right?

So the two stars have the same mass, but if their sizes are 100 times smaller density scale but – that is sort of the cuable size, and therefore Sirius B is a million times more dense than Sirius A.

So this is the first, you know, essentially the first discovered white dwarf although it was not plotted on a Hertzsprung-Russell diagram at the time, Sirius B, one of the stars right here in our backyard.

And what these stars are is they are the end product of stellar evolution. So this is the death of the bulk of stars that form our galaxy. After they exhaust all of their hydrogen supply they have no more nuclear energy burning sources so they cannot continue to sustain a high luminosity. And over time, they simply cool and fade becoming dimmer as time passes on.

So if we go to the next slide, you know, we can compare a white dwarf. If we consider the composition of a white dwarf, it is a product of hydrogen and helium burning reactions. And those hydrogen and helium burning reactions eventually form carbon.

And carbon at high extreme pressures is actually a diamond. That is what a diamond is. So this is an artist's depiction of a white dwarf on the right hand side with a diamond in the middle.

And we can compare and contrast the properties of the white dwarf with for example the Golden Jubilee Diamond which is probably the most brilliant diamond ever discovered on earth.

So let us see who wins in some of these categories. So if you look at the discovery first, for the Golden Jubilee Diamond, it was found in 1985. Well the white dwarf beats that by almost100 years.

If you look at the size, the Golden Jubilee Diamond is about five centimeters which is pretty big actually if you think about it, five centimeters across. While white dwarf it is about a billion centimeters, okay? So it is huge.

The mass again, the Golden Jubilee Diamond only weighs about 100 grams or .1 kilograms. The white dwarf weighs about the mass of the sun, half the mass of the sun so it wins there. The density the white dwarf is much more dense.

But if you consider the value, the Golden Jubilee Diamond is worth about $10 million U.S. dollars. Your average run of the mill white dwarf not worth a lot.

And if you go to the next slide, you can see in the bottom row the finder's fee if somebody finds a diamond like the Golden Jubilee Diamond or somebody sells it, they make a lot of money whereas an astronomer like me, I find white dwarfs, well my salary is definitely much, much less than $10 million U.S.

Okay, so let us go to the next slide.

Carolyn Slivinski: No editorializing please.

Jason Kalirai: So a few reasons we want to study these dead stars. First of all as I mentioned, most stars in the universe that form more stars as a byproduct of star formation are low mass stars. And in fact 97% of all stars will end up making white dwarfs.

The brilliant super nova explosions we see, the stars that make neutron stars and black holes are a tiny fraction of the overall stellar budget. It is only a few percent of all stars.

So if you look at old stellar populations, most of those stars have already made white dwarfs. And the only way that we can really understand the properties of those first generation stars, what their mass distributions were, what their ages are, what their properties are sometimes involves studying white dwarfs because we have no way to actually probe what the hydrogen burning states of those first generation stars were.

Second reason is that white dwarfs are very simple unlike main sequence stars that are burning hydrogen. White dwarfs do not have any more nuclear burning sources. So over time all they do is take whatever stored thermal energy is left in their ions and they radiate that stored thermal energy into space.

And therefore they are governed by very simple physics and they cool predictably with time. And in fact what this means is by simply measuring the luminosity of a white dwarf, by simply measuring what it is – how much light it emits, you can measure what the age of that star is.

So you can use these systems as clocks to date stellar populations. So if you can uncover white dwarfs in a nearby stellar population like a star cluster, you can go ahead and determine what the ages of those star clusters are simply by measuring the luminosity function of the white dwarfs.

A third reason is that, you know, when we looked at this cartoon diagram of what the eventual end fate of the stars are going to be as a function of their mass, there is a very important transition between, you know, where a star actually becomes a type 2 super nova and where it becomes a white dwarf.

So a type 2 super nova is this massive event and it is believed to occur in stars that are about ten times the mass of the sun or higher and anything with less mass than that will make a white dwarf.

But that number, that ten polar mass number is very poorly constrained both observationally and theoretically. And a neat way that you can get at that number is by probing what the most massive star is that will make a white dwarf. That is a much easier measurement to make and there is a lot of active research right now in trying to define where this is.

And four and five relate to probably the most widespread application of studying white dwarfs. That is, you know, white dwarfs are the end product of stellar evolution. And by measuring their properties and linking those properties to the stars that made the white dwarfs, we can directly constrain stellar evolution model.

We can directly determine how stars evolve, how much mass they lose through their evolution and what their properties are as they are evolving like their colors.

And this is something that feeds into general astrophysics. Often in astronomy we are looking at distant galaxies and other phenomena in the distant's universe.

And what we want to know is measure their masses, their ages, their (metalicities), how much dark matter they have. All of those measurements rest on our fundamental understanding of basic stellar evolution, how the stars in those galaxies that are responsible for that light are evolving.

And one of the neat ways that you can constrain that is through the study of white dwarf dwarfs are very faint. So if you do just blind survey, if you point your telescopes in some random area of the sky, the chances of you actually finding one are pretty slim.

Fortunately, many stars do not form on their own in the galaxy, they form in clusters. And there are several different kinds of clusters. We believe in fact the sun, you know, our own sun formed an aloose stellar association, something like the picture that you see on the left hand side which is a very sparse sample of, you know, tens of stars of maybe100 stars in a small region of space that are very loosely gravitationally bound.

Another example of a star cluster is something that we call open star cluster. There are thousands of these open star clusters in our galaxy. These are intermediate aged systems that contain thousands of stars in a small region of sky.

And then on the right hand side are these – these really these beasts, these exotic stellar population called globular star clusters. There is only about 100, 150 systems in the Milky Way galaxy that we know about. But these are, you know, this is millions of stars, hundreds of thousands up to a million stars in a small region of space.

So if you take the distance between the sun and the nearest star to the sun, within that distance in a globular cluster, there would be tens of thousands of stars.

So if the earth was born in a globular cluster, you know, it would be daylight 24 hours a day because we would always have a different star, a different sun that would be shining light upon us.

So these globular star clusters are very interesting because they are, you know, these are systems that we believe formed at the same time. So all of the stars formed at the same time but they have a huge spectrum and mass.

They are also stars that have the same chemical composition because all of these stars form from the same molecular cloud that made the stars.

And finally, we believe that if we look at galaxy formation simulations, how galaxies form, we believe these globular star clusters are among the first systems that ever formed in galaxies.

So astronomers began, you know, really in the ‘80s pointing their telescopes at these globular clusters and attempting to characterize what the (plattometry) of all of these stars were in these systems.

And if we go to the next slide we see a typical Hertzsprung-Russell diagram of a globular cluster. So again on the Y axis here it is just the luminosity of the stars and on the X axis is actually plotted the color of the stars here, but that – the color is just a proxy for temperature so the hotter stars are on the left and cooler stars on the right.

So the sequence that you see sort of from the middle of the diagram to the bottom is a main sequence. Those are the hydrogen burning stars in the cluster. And then the little branch that you see shooting off into the top right part of the diagram are the giants. Those are the red giants in this cluster.

Now what you do not see in this diagram is you do not see any faint blue stars, right? There is a lack of faint blue points. In fact there are none implying that there are no white dwarfs in this cluster.

But what really is happening here is that the polarimetry is simply not deep enough, right? The white dwarfs cool very quickly. I mean they have luminosities that are much lower than these main sequence stars and these giant stars and therefore we really need a telescope like Hubble to go in and probe to ultra faint magnitudes to actually uncover these stars in these globular star clusters.

So if we go to the next slide, slide number 12, we see a diagram that is actually – this is a theoretical diagram. These are not observations that are shown in the bottom right.

So this is again, this is showing snapshots, three snapshots of what the bottom – what the lower left hand part of the color magnitude diagram or the Hertzsprung-Russell diagram would look like in a globular cluster if you could actually go in and measure the stars.

So what we are doing right now is just focusing in on the cool blue stars on the diagram. And you see these wonderful sequences as a function of age. So the sequence that you see on the left is what theoretically you might expect for a white dwarf cooling sequence that has an age of 10 billion years.

So, all of those individual dots that you see are individual white dwarfs that are cooling in that diagram.

And the middle diagram is for an age of 11-1/2 giga-years. And the diagram on the right hand side is for an age of 13 giga-years, meaning billions of years.

So what you see is that the morphology of these diagrams changes and as you go to older ages, the white dwarfs have had time to cool to fainter magnitudes and therefore they are found lower on the diagram.

So the way that you can measure the ages of these star clusters is by actually going in and finding these faintest white dwarfs. And the only way that you can only measure the age is if you are confident that there are in fact no even fainter, even cooler white dwarfs in these diagrams.

So we proposed, several years ago, to use the Hubble Space Telescope with the existing imaging camera, the WFPC2 camera that was on Hubble at the time. And we were awarded, you know, a 130, 123 orbits of Hubble Space Telescope which is a huge allocation telescope time to at that time construct the faintest image that had ever been produced in astronomy and use it to find white dwarfs in the nearest globular star cluster. And that is a system called Messier 4.

We followed that study up by going to another globular star cluster that is also nearby. Its name is NGC 6397. We did this just a few years ago. And the goal here was again to catalog the faintest white dwarfs, construct a very deep image of the star cluster.

And this time the star cluster had different properties. It was a dynamically different star cluster. It has a different metalicity than Messier 4 and we were awarded that time.

And just now in cycle 17, this upcoming cycle after the successful servicing mission that we had about a month ago, we have received time again now to go to an even different cluster with different properties called 47 Tuck which is a very famous cluster and we will be conducting these observations again.

So if we go to the next slide, we can see an image, what a typical very deep image looks like in astronomy. This is probably the most famous image that the Hubble Space Telescope has ever obtained. It is called the Hubble Ultra Deep Field, okay?

So this is an image of a tiny region of space through a sort of un-obscured region where there are few stars. And, you know, Hubble sat on this one field for hundreds of orbits and integrated collecting photons from these distant sources. And in fact every single dot that you see in this image, almost every single dot that you see in this image is a galaxy, not a star.

Even those faint little puny dots that you see littered all over the image are distant galaxies and not stars, okay? There are a few stars in the image. If you look at the – right at the bottom there is a little blue object in the middle that has these spikes, these vertical and horizontal spikes. Those are actually the fraction spikes caused by a saturated star. So that is a star.

Then there is another one just above it sort of an orange star about maybe a fifth of the image up in the middle. That is also a star. But in general, almost everything you see in this image is a galaxy. So this is what a deep image looks like if you point your telescope in a region of space where there are no foreground stars.

If you go to the next slide, you see the opposite. You see what an image looks like if you point right in the heart of a nearby globular cluster. And now you can see that almost every single dot that you have in this image is in fact a star.

You know, there is still – if you look closely, there are still some galaxies that you can see peeking behind the stars in the distant universe, but almost every dot is in fact a nearby star.

Now whenever you – one of the very interesting things is whenever you obtain a very deep image in astronomy, you are bound to find something that you are not expecting, okay? So some serendipitous discovery for example.

So if you go to the next slide, you can see half of the same image. And one of the first tests that we did to try and find white dwarfs in this image, before we ever constructed a Hertzsprung-Russell diagram from these data, were that we just, you know, took everything that was considered faint and blue. So any faint blue star and we called it a white dwarf.

If you look at the Hertzsprung-Russell diagram, objects that are fainted blue should be on the white dwarf cooling sequence. And when we did this, we found a whole bunch of stars, we found hundreds of starts in this image that look like they are white dwarfs. And they in general formed this distribution where there is more of them in the top right hand part of the image and less of them in the bottom left hand.

And we expect that because the density of the cluster is changing across the field of view. We are not looking right at the center of this cluster, so the center is actually off the top left and the periphery is off to the top – bottom right.

But we were surprised because we found – if you click one more slide, you see that there is this big elliptical galaxy in this image and the point source enhancement, the little faint dots that we found around this elliptical galaxy, the numbers of those dots was huge around that galaxy relative to anywhere else on this image.

So these are faint blue objects that we initially confused as white dwarfs. But when we looked at the special distribution, there is no physical reason to expect white dwarfs in the cluster to be centered in a small region of space.

And these faint dots that you see are actually globular clusters themselves that are orbiting that galaxy. Okay? So this is a very interesting observation because this is one of the deepest images ever taken in astronomy, and these faint dots that you see here, these globular clusters that belong to that galaxy, are among the faintest objects that we found in this image, and therefore, you know, this galaxy must be the most – one of the most distant galaxies in which anybody has ever found globular clusters.

And we followed this observation, this initial HST observation up with some ground based spectroscopic observations to confirm that the red shift of this galaxy is such that these are in fact the most distant globular clusters that have ever been cataloged in a galaxy.

This is not something that, you know, we expected to find. This is just a serendipitous discovery because we have such a deep image in these data sets.

And I have only circled about five of those globular clusters. But in fact, if you do the statistics, there are about 150 of them that we detected in this image around that galaxy.

Okay. So if you go to the next image…

Carolyn Slivinski: All right we are on slide 16 now.

Jason Kalirai: Okay. So if you go to this next image, you can see what is probably considered the nicest and cleanest Hertzsprung-Russell diagram that has ever been published in astronomy.

This is, you know, this is a result of that very deep image that we produced. You can see a very clear pencil thin main sequence in the Hertzsprung-Russell diagram. And that main sequence extends to very faint magnitudes and then gets lost in these foreground and background stars that you see.

So all of those points that you see that are not on that wavy line, that wavy curve in the center of that diagram are stars that are either in front of the cluster or behind the cluster that are not members of the cluster.

And probably – and you can see the red giant on the top part of the diagram as well. And probably the most amazing feature of this diagram is this huge, you know, rich sequence that we see in the bottom right part of the diagram, which is the complete white dwarf cooling sequence of this star cluster.

And there is literally – there are hundreds of white dwarfs that we found in this Hubble image. And this white dwarf cooling sequence has a very distinct shape to it. You see that the stars become, you know, cooler and fainter. And then right at the bottom end, they make this hook to the blue.

And this is the hook that has been theoretically predicted for over a decade now. And it is something that – it is a bit technical. It is something that is caused by the capacity in a very cool star changing.

And the predictions from the theoretical models in the mid '90s were that as a white dwarf's temperature drops to about 3 or 4000 degrees Calvin, you would form molecular hydrogen in the path – in the atmosphere of the star and that molecular hydrogen can cause the flux of the star to become bluer and therefore these things curve to the blue.

This has never been seen observationally. And this deep image verified that theoretical model. And at the same time, provides us with a sample of the faintest white dwarfs in the star cluster.

Now very interesting is what you can do with kinematics. Now these globular star clusters are in the halo of the Milky Way and they have large velocities relative to the sun.

So if you flip to the next slide, you see on the left hand side something that astronomers call a proper motion diagram. So this is a diagram that simply plots. It is a very simple diagram. It plots the motions of all stars as measured by comparing the image that we obtained with Hubble for this cluster to a shallower image that was obtained about ten years ago through a different project with Hubble.

And when we compare those two images, we see that, you know, a lot of the stars form the diffuse clump that is centered at zero zero in the diagram. And most of the stars form this tight clump that is off to the bottom left of the diagram.

So what is being plotted is simply the proper motion – the motions of stars per year. And what this does is it actually provides us a way based entirely on the way that stars are moving to isolate those stars that are actually part of the cluster from those that are not a part of the cluster.

So if you flip one more slide, I just put a little circle, a little red circle around the stars that look like they are a part of the cluster and if you go one more slide, we are going to plot just those stars on the Hertzsprung-Russell diagram.

And what you see is all of that – all of those nearby faint nearby and distant stars that were surrounding this thin sequence disappeared. Right? So simply by selecting stars based on their motions, we can construct a very clean study of the actual stars that are members of the star cluster.

And what you see here is, you know, one of the very interesting things is this trail of stars that you see in the bottom right hand part of the diagram. All of that trail, that little trickle of five or six data points in the bottom right hand between sort of a color of three and four are members, proper motion members of the cluster and those stars actually have masses that are right at the hydrogen burning limit.

So those are the lowest mass stars that will ever burn hydrogen in their cores. So this is actually – we published a paper on this study characterizing where the hydrogen burning limit is in a globular cluster such as this.

One of the other things that you see is that we have lost a lot of the stars in that hook part of the white dwarf cooling sequence. That is not because those stars are not members of the cluster, it is because the shallower exposures from ten years ago were too faint to actually measure those stars.

So we have no way of measuring a position for them. We have no way of measuring a velocity for them. In fact those stars are members of the star cluster.

So if we go one more slide, we can actually – let me take a quick detour before we get to the main results from this study. If you look at these Hertzsprung-Russell diagrams, this is another, just a cartoon Hertzsprung-Russell diagram, there is one very easy test you can do to confirm whether or not the objects that you are measuring are in fact white dwarfs.

The white dwarfs have the same color as some main sequence stars, right? If you look at this diagram, you can see that – if we – actually if you hit the one more slide forward, I have isolated a set of stars that have the same color and therefore have the same temperature.

But at the top part of this diagram, those stars with the same temperature can be giants. In the middle part of the diagram those stars can be main sequence stars that are burning hydrogen in their core. And at the faint end of the diagram, those stars are white dwarfs.

The difference is that the gravity is changing immensely. In these giants at the top of the diagram, the gravities are very low, the pressures are very low. And as you go to main sequence stars, the dwarfs, they have a more of a gravity.

And when you go to these white dwarfs, these white dwarfs are a million times more dense than stars like the sun, and therefore their gravities are huge and there is a lot of pressure.

And what that does is it produces these distinct signatures in the spectrum of stars. So if you flip one more slide, I illustrate what a spectrum of a star looks like at the same temperature as you march down this diagram. So at the top when you look at the spectrum of these (A) type stars as we call them that are giants, you see the hydrogen bomber lines, right?

So these are just hydrogen absorption lines. And these absorption lines are very narrow. And as you march down the diagram to the main sequence stars and the white dwarfs, you see the same bomber lines because these stars have the same temperatures so they should have the same, you know, atomic species that is peaking in the atmosphere, but the shapes of those lines change drastically.

In the white dwarf because of the high gravity, the lines are actually pressure broadened. And what that means is that the hydrogen atoms in a white dwarf are actually interacting with one another. And the perturbations caused by these neighboring interactions cause these lines to be very, very broad relative to normal main sequence stars.

So when you see a signature like this in the spectrum of a white – of a star, you know it has to be a white dwarf. And if you go to the next slide, I just want to highlight how we verified in star clusters like NGC 6397 that all of those stars that are on the white dwarf cooling sequence, especially at the bright part of the white dwarf's cooling sequence based on spectroscopy, sort of the figure on the right on the left hand side, you can see spectra for actual stars in nearby globular clusters that show these pressure broadened hydrogen bomber lines.

And therefore we know that these have to be – these are in fact white dwarf stars.

Okay. So if we get to the punch line, if we go to the next slide, you know, we can actually use these white dwarf cooling sequences that we measured in these data and compare and contrast it to the theoretical models that I showed earlier and I show again in the middle of this diagram.

And sorry this is a bit faint, but the diagram on the right illustrates – so the solid current that you see in the diagram on the right and the dash curve and the solid curve are actual models, okay?

And the data points that you see the little filled circles are the observations, the observations of white dwarfs in this data sense.

So what is being plotted here on the Y axis is just a number of stars, and on the X axis is the luminosity, where luminosity is becoming fainter toward the right hand side. So you see that at the sort of at the right hand – at the left hand part of the diagram, there are very few bright white dwarfs. And as you march to fainter and fainter luminosities, as you move to the right, you pick up more and more of these stars.

And when we compare the number of counts that we have to the theoretical models, we can conclude what the age of the star cluster is. And what we have done is we have done the study now in Messier 4 and NGC 6397 as I mentioned.

And for both clusters we find that the best models that fit the white dwarf cooling sequence is and from the faintest white dwarfs in the star cluster suggest that these globular star clusters formed 12 billion years ago.

So if we look at cosmology, we know that the universe formed about 13.7 billion years ago. And since we know that globular star clusters are among the first systems to form in galaxies, when galaxy formation happens, this implies that the first stars in our galaxy formed about 1.7 billion years after the Big Bang. The first stars that we can at least see today.

If we repeat – interestingly, if we repeat the same types of studies in the disk, right, so we can look at star clusters that are not in the halo of our galaxy but star clusters that are in the disk or we can even look at field stars in the disk of our galaxy, and we use the same white dwarf cooling theory approach on measuring what the ages of those structure are, we find that the disk of our galaxy only formed about 8 billion years ago.

So the disk of our galaxy formed much after the halo of our galaxy. So these are sort of fundamental constraints in better understanding how galaxy formation proceeded.

And interestingly, one point that I forgot to mention is if you look at those white dwarfs in this ultra deep Hubble Space Telescope image, those white dwarfs are about a billion times fainter than the faintest stars that we can see with the naked eye.

So that is how sensitive Hubble's eyes are to find objects such as this. They are a billion times fainter than the faintest star that we can see with the naked eye which is really a remarkable measurement that we owe – we obviously owe credit to Hubble for that.

So if we go to the next slide, I just wanted to highlight how, you know, the Hubble Space Telescope in the last several year, last five six years, has been used for over 400 orbits to probe white dwarf populations in some of these nearby star clusters.

So the Messier 4 and the NGC 6397 diagrams that you see on the left hand side are diagrams that our team has constructed. The 47 Tuck diagram that you see, the third one over, is actually a very interesting diagram.

This is – 47 Tuck is this nearby globular star cluster that sits in front of a dwarf galaxy in the Milky Way. And this dwarf galaxy is called a small Magellanic cloud. So that dominant sequence that you see in the 47 Tuck diagram on the left hand side is actually the main sequence of the 47 Tuck.

The bluish, the most blue sequence that you see is a white dwarf cooling sequence of 47 Tuck. And then that rich sequence that you see in the middle is actually the main sequence of stars that are in this other dwarf galaxy, the small Magellanic cloud.

And this is a very distant galaxy that is orbiting the Milky Way. And this is, in fact it is a very deep diagram but it is shallow relative to what we are going to construct in cycle 17 in the upcoming cycle where we will actually measure the complete white dwarf sequences of cluster and the hydrogen burning limit both in 47 Tuck and in the small Magellanic cloud.

And the figure that you see on the right hand side is the most massive globular star cluster known in the universe, a cluster called Omega Cen which is a very massive beast. And there has also been a deep Hubble Space Telescope study of that star cluster and many white dwarfs have been cataloged in that star cluster and we are hoping to even push that diagram down fainter and measure when Omega Cen formed through white dwarf cooling theory.

Okay. So that is basically the end of the talk. And I think if you go to the next slide, that will be the final slide so that is it. So thank you very much.

Carolyn Slivinski: So let us see if we have any more questions now, or any questions to begin.

Woman: I have a question. This is…

Man: I have a question.

Carolyn Slivinski: Okay. Let us start with the woman who was speaking first.

Tish Bresee: Tish Bresee from Kopernik Observatory in Vestal, New York. Hello Jason?

Jason Kalirai: Yes. Hi.

Tish Bresee: Could we go back to Sirius A and B for a minute?

Jason Kalirai: Yes. Sure.

Tish Bresee: I congratulate you on your series on white dwarfs. That is really cool. How is it possible – they have already done it, right?

Jason Kalirai: Yes.

Tish Bresee: How is it possible that one has evolved so differently than the other?

Jason Kalirai: Ah because – so their masses are different. So if – Sirius A has a larger mass than Sirius – sorry, Sirius B had larger mass that Sirius A. And therefore, Sirius B exhausted its hydrogen supply faster than Sirius A.

So the two stars were born at the same time but because one was more massive, it evolved faster and went through all of its giant phases and cooled to become a white dwarf while Sirius A is still burning hydrogen on the main sequence.

Tish Bresee: Okay that is great. Thank you.

Jason Kalirai: And there was a second question I believe.

Man: Yes. This is two part question.

Jason Kalirai: Sure.

Man: One, what type of radiation is emitted from a dwarf – white dwarf. And also if you were to kind of slice a white dwarf in half, could you describe a little bit of the interior going from the core out…

Jason Kalirai: Yes of course.

Man: …of matter.

Jason Kalirai: Sure. So the white dwarfs are products of – so what happens in the core of a star is as I mentioned on the main sequence the star is burning hydrogen into helium through fusion reactions. And that is how the star sustains its energy because the little bit of mass that is left over from that reaction is converted to energy. It is basically E=MC2.

After that core hydrogen burning phase, at a post main sequence phase, the star will actually burn helium in its core. And that helium will turn into carbon, okay? And if the carbon burns a little bit, the carbon can actually turn into oxygen, but beyond that the star does not have enough mass, does not have enough pressure and gravity to fuse that oxygen into something else.

So the white dwarf, the core of the star, because it is a byproduct of those phases contains carbon and oxygen. And a lower massed white dwarf will contain more carbon. A higher massed white dwarf will contain more oxygen.

Surrounding that carbon and oxygen core is a thick layer of helium. And that is helium that was not burnt away in the previous generation star. And then in some white dwarfs, there is a very thin, you know, by very thin I mean it will be like, you know, one-ten thousandth of the mass of the star. Very thin layer of hydrogen on the surface of the star, and that hydrogen on the surface of the star is responsible for those bomber lines that I showed in the spectrum of white dwarfs.

And what is interesting is that only some stars show that hydrogen layer. And it is a popular question in astronomy to gauge why only some stars show that hydrogen.

Either some stars are inefficient at burning the last or residual hydrogen that is leftover in the post main sequence phases or it is possible that because of the orbits of these stars whether they are in star clusters or whether they are orbiting our galaxy, that they accrete some hydrogen onto their surface from the interstellar medium. So that is the general structure of a white dwarf.

The radiation is simple. You know, I mean within the core of the star it is really – it is even conduction. You know, there are no diffusion processes in these stars. So in the core it is even conduction because the – basically the atoms are so tightly packed together.

But for most white dwarfs from the surface you basically just have heat that is escaping from the star so it is like a black body radiation. So it is a standard electromagnetic radiation.

Any stored thermal energy that is left in the ions of the star is being released into space over time and the star cannot generate any more energy on its own.

Man: So they could be approached?

Jason Kalirai: They are still pretty hot actually, so, you know, eventually the star would be, you know, it will continue to cool and it will have a temperature that I guess you could approach it at. But, you know, the coolest white dwarfs that have been found in the galaxy still have temperatures of 3 or 4000 degrees. And the reason that I refer to that as a cool temperature, I mean the surface temperature of the sun is only 5800 Calvin, is because these stars, you know, when they finish those post main sequence burning phases had temperatures that were 100,000 Calvin.

And they went from 100,000 Calvin down to their present temperatures which are a few thousand Calvins. So they are still pretty hot actually.

Man: Thank you.

Jason Kalirai: Are there any other questions?

Robert Bigelow: Yes. This is Robert Bigelow from Salt Lake City. Just had a question, I know astronomers sometimes use the cutoff point on the main sequence of an HR diagram…

Jason Kalirai: Yes.

Robert Bigelow: …to determine the age of a globular cluster.

Jason Kalirai: That is right.

Robert Bigelow: Is – have you compared your age based on the white dwarf's data and compare that with the age of the clusters and do they correspond?

Jason Kalirai: Yes, absolutely. That is actually a great question. And that is actually – that question is actually why these observations were conducted in the first place because what happens is that age that you measure, it is called – the termination point that you mentioned on the main sequence is called a turn off.

And the age that you measure from the turn off of a star cluster from this sort of this hook on the main sequence is the most popular method for dating stellar populations.

The problem is that the physics involved in main sequence stars are much more complicated than white dwarfs. When you look at main sequence stars you have diffusion processes, you have settling, you have metals, you have rotation and all of those affects produce different behavior of stars as they are evolving.

So depending on whose theoretical model you use to compare your main sequence turn off to, you get a wide dispersion in ages from the main sequence turn off.

The white dwarfs have their own systematics, but they are completely different systematics and the physics is much simpler.

So the reason that we made these measurements were actually to resolve some of the differences in ages that we see in the main sequence turn off of different star clusters.

And the white dwarfs do not care about this. The rotation rates are small. Diffusion is not a problem because the gravity is so high. The metals – the metals all just sink, right? Only hydrogen can stay at the surface of the star. The metals are too heavy. They sink.

So the physics are governed and the cooling rates are governed by simple processes.

But in fact if you go ahead and you compare the white dwarf cooling ages that we measured, the 12 billion year old number, it is consistent with the main sequence turn off ages for the two star cluster that we have looked at.

Robert Bigelow: Thank you.

Jason Kalirai: But the error bar on the age is smaller with the white dwarf so it is a more accurate measurement.

Robert Bigelow: Okay great. Thank you.

Jason Kalirai: Other questions?

Carolyn Slivinski: Well this is Carolyn. I have a question for you. Now that the fourth servicing mission is complete and was quite a success, what does that mean to you as far as losing WFPC2, things like that? What is the prognosis for how your research goes forward with new instruments?

Jason Kalirai: Yes. So it is actually very exciting. And I was fortunate enough to go to Florida for the shuttle launch that carried the new instruments. And we are very excited that the servicing mission was successful.

So it is actually very interesting because if you look at instruments in astronomy, before an instrument actually ever sees a photon in space, you know, the plans for constructing that instrument were probably laid out 15, 20 years before that point.

So when you look at these older cameras like WFPC2 which has now been replaced by this new WFPC3 camera, the sensitivity, the wavelength range, the resolution of the new cameras is amazing compared to these older cameras.

So, you know, this new camera, WFPC3, I am actually an instrument scientist for that camera here at the Institute, but this camera will be the workhorse of the Hubble Space Telescope. It will, you know it carries more than 50% of the observations that will be undertaken in the next cycle.

It has amazing sensitivity in the ultraviolet and the red, has high resolution, has a large field of view. So it is going to be great for all of the science. It is going to be wonderful.

And the other thing is that the diagram that I showed for NGC 6397 was actually constructed with the advanced camera for surveys which is another camera on the Hubble Space Telescope. And that camera had malfunctioned about two years ago and that camera has been repaired in the servicing mission and it looks like everything is fine and it is going to work correctly we hope.

The first data from that camera will be coming in in the coming weeks. And that is the camera that we will actually target the next cluster 47 Tuck with.

And even more exciting is that you can use these two cameras at the same time. So while you are looking at some field in your star cluster with this advanced camera for surveys, you can also turn on the WFPC3, the brand new camera, and look at a different part of the cluster simultaneously.

So we will actually have the best of both worlds and be able to observe the star cluster with both cameras.

Anita Sohus: Carolyn this is Anita.

Carolyn Slivinski: Yes.

Anita Sohus: Are there any educational activities related to what they presented today?

Jason Kalirai: I mean I spend a lot of time visiting local schools, you know, conducting science fairs all over Baltimore City, plugging astronomy to the youth. And usually when I do that, I try and highlight some actual observations that we are taking with the Hubble Space Telescope. So I think in that regard there is.

The Institute is also wonderful because the Institute has a huge office of public outreach and they can actually provide us with a lot of material to hand out to the students that really gets the students excited.

And when I go and give talks, I actually tailor the talk to some of my own science, even for, you know, grade four students. And I have the office of public outreach provide me with, you know, lithographs, and astronomy tattoos, astronomy playing cards that have the same images that I am showing in my talk.

So I think in that respect there definitely is some sort of outreach activities that go along with these science cases. All of that said, you know, a hundred orbits on Hubble is a huge investment of telescope time. It comes with a huge, you know, sort of grant for the scientists that are conducting the observations.

And I think all of us need to think of more clever techniques of, you know, exploiting those data and getting the youth more excited about that. I think that is something that all astronomers need to be thinking about some more.

Anita Sohus: Thank you. I appreciate that. And I wanted to make a plug for before the conversation started, someone was asking for a lithograph on Hubble and I have posted a link to that on the site where you downloaded the PowerPoint for today.

Jason Kalirai: Great.

Anita Sohus: And that site is actually Amazing Space site.

Jason Kalirai: Yes. I have been there many times.

Anita Sohus: Yes. So everybody, especially the gentleman who was looking for the Hubble lithograph, there is a link directly to it that he can also explore that site for materials.

Jason Kalirai: Great. And I can also recommend the Hubble Heritage site if you just Google Hubble Heritage you can download images of all of the popular targets that Hubble has ever looked at.

Woman: Just…

Jason Kalirai: Sorry.

Woman: our youth center.

Jason Kalirai: Our youth center as well. Okay great. Yes. The youth center as well on STScI Web page.

Anita Sohus: Terrific – do we have other questions for Jason today? Doesn't sound like it.

Thank you so much, really appreciate it. And I want to remind everybody that tomorrow we have our last pre-launch telecon for the lunar reconnaissance orbiter. And that will be at 2:00 pm Eastern tomorrow. Kay and I have (unintelligible) notes about that.

Man: Excuse me.

Anita Sohus: yes.

Man: Will there be a transcript of this call?

Anita Sohus: Yes.

Man: Fantastic. Thank you.

Anita Sohus: It is too much to absorb sometimes…

Jason Kalirai: Yes. Sorry about that.

Anita Sohus: But thank you for using some really great visuals in your presentation as well.

Jason Kalirai: Thanks a lot. I appreciate that. And also…

Earl Kyle: One last question.

Jason Kalirai: …feel free to email me if you have any questions or if you think of anything afterwards as well.

Earl Kyle: Oh okay.

Anita Sohus: I think we have someone here yes.

Jason Kalirai: Okay.

Earl Kyle: Well I did. This is Earl Kyle in Rochester, Minnesota. Can you point me to any PowerPoint presentations that at let us say the eighth grade level, make it a little more understandable about these various nuclear sequences as the star builds up to the heavier elements? I found things but the things that I have found out on the Internet are a little too advanced for the eighth grade audience target that I am looking for.

Jason Kalirai: I think I am going to let outreach office handle that one.

Carolyn Slivinski: I am not personally aware. This is Carolyn. I am not personally aware of any PowerPoints like that. I think probably what you found in your searching is a result of the issue of trying to teach a topic like that to the younger ages. It is an advanced topic. So I am not aware of any at that age.

Earl Kyle: Okay.

Woman: I have done some modeling where I have used beads, actually beads on CDs where I have created atoms.

Earl Kyle: Oh.

Woman: And if you – I think you can show the building of like a hydrogen to a helium…

Earl Kyle: Sure.

Woman: …and helium to hydrogen and then build from that to – I mean basically all you are doing is adding protons and electrons and neutrons. And I think that…

Earl Kyle: Yes. What I am looking for though is not high – not the end result, but the steps that how you get there. So…

Woman: I am thinking that that is how you get there is you go from the helium. You build that with the one proton, one neutron, one electron. Then you go to the – you just add protons and neutrons until you get to the let us say the oxygen.

Carolyn Slivinski: Can I just suggest that this would be a great topic for the (listener) to put ideas out there and requests for activities?

Woman: Okay.

Anita Sohus: Yes. If people do have some ideas, if you will send them to me I am happy to post them on the Web site too. We do not quite have a chat room open and sometimes I love conversations with a (listener) but people with small mailboxes do not. So we have to kind of balance how much we do with that right now, although I am hoping to get more capacity.

Woman: Yes. Any good suggestions that come in will be posted on the training pages.

Man: Excuse me. The person who was talking about – I am sorry I don't know you name now, I forgot it – where you put the Hubble lithograph link on the site.

Anita Sohus: Yes.

Man: I think it has – it has turned into one of those mail to links. It is trying to send an email instead of go to a site so…

Anita Sohus: What?

Man: …you might want to check that. I tried to debug it and that is all the beeping you have been hearing here. Sorry, but I give up.

Carolyn Slivinski: Go ahead and Google amazing dash space and that should get you there.

Man: Thank you very much.

Carolyn Slivinski: Sure.

Anita Sohus: Thank you. I will fix the link right now. How did that happen? I was…

Carolyn Slivinski: Amazing Space will not answer your email.

Anita Sohus: But Carolyn will.

Man: And I know this was just a test to see if we were really using it. So I know.

Carolyn Slivinski: There you go.

Anita Sohus: It was. It was. It worked.

Carolyn Slivinski: You passed.

Anita Sohus: Okay. I will fix that right now. So with that, I guess we will log off for today.

Jason Kalirai: Okay. Thanks a lot everybody.

Anita Sohus: Thanks for today.

Carolyn Slivinski: Thanks for attending.

Man: Thank you.

Anita Sohus: Bye.

END