NASA Museum Alliance
Hubble Science Briefing
Seeing Hubble's Universe: Making Pictures from Data
Zolt Levay

Moderator: Anita Sohus
March 6, 2008
2:30 pm CT

Kay Ferrari: Good afternoon everybody. This is our Hubble Briefing for the Museum
                      Alliance. This is Kay Ferrari sitting in for Anita Sohus. And I'm going to turn
                      the program over to the Space Telescope folks who will introduce the speaker.

Frank Summers: Good afternoon everybody. I'm Frank Summers, an astronomer here in the
                      Office of Public Outreach who, along with John Stoke organizes these Hubble
                      Science Briefings for you every month. And besides that we like to run these
                      briefings not as a presentation where our speaker just speaks at you and you
                      just sit back quietly and listen but more as the idea of a conversation.

                      I will be rude and interrupt my speaker a bunch of times and say, "Hey,
                      anybody have any questions?" And we'll also, just so that everybody stays on
                      the same page, announce, "Okay, next slide." And you'll also notice that we
                      have put these ugly graphics in the lower left, we call page numbers, that Zolt
                      didn't have on his original slides but I had to put them there just so that
                      everybody can keep in touch and be on the same page.

                      Our speaker today – I have variously described as one of the most powerful
                      men in astronomy simply because he is the guy who determines what the
                      public thinks the Hubble images really look like. His job, in the Office of
                      Public Outreach, is as the main image processor to take the Hubble science
                      data and turn it into the Hubble press release pictures. And that's what he's
                      going to talk to you about today. Without further ado, the most important man
                      in astronomy, from one point of view at least, Zolt Levay.

Zolt Levay: Thanks, Frank. Hello everybody. I don't think I can live up to that
                      introduction but in any case I just want to talk today a little bit about, as Frank
                      said, how we get from the data from Hubble Space Telescope to the pretty
                      pictures that everyone sees all over the place, online and in magazines and so
                      forth.

                      We go to the first slide…

Frank Summers: It has the wonderful little number 2 in the lower left corner.

Zolt Levay: This is more or less what a basic Hubble Space Telescope picture looks like. Our job is to go from this to the next slide, which is a color picture of the same object. As you might imagine, Hubble is not exactly your basic point and shoot camera. We don't get pretty color pictures down directly from the telescope.

The cameras, various imaging instruments on the telescope make black and white imagines. And so we have to take these images and work with them and go through, you know, some processing to get the pictures that you see. So for the rest of this we'll talk a little bit about some of the considerations that go into that, some of the choices that we make along the way.

We go to the next slide.

Frank Summers: Slide 4.

Zolt Levay: Just some thoughts behind this. First of all, as we've said, we're starting with data. The Hubble Space Telescope was not really designed to make pretty pictures. The pretty pictures are kind of a by-product of the data that the astronomers get out of the telescope. The telescope was designed to do leading-edge science – arguably the best telescope ever made.

Being above the atmosphere is a big advantage. We don't have the distortion of the atmosphere to contend with. But in any case the data that we get from the telescope is designed to do astronomy; for astronomers to analyze and figure out what's going on in these objects that we're looking at.

But as a nice by-product we can make pictures because this is imaging data. Not all of it, but much of it is imaging data and really high quality imaging data so we can make some pictures out of them.

The way we do that is, more often than not, to take numerous exposures from the telescope, combine them in various ways, work with the numbers a little bit and that's the details are what we'll talk about a little later. And ultimately reconstruct color images from these data.

The images are not intrinsically color; there's no color information in any single image. The only color information would be the filter that's in the camera. The cameras include numerous color filters, which isolate various parts of the spectrum, which the astronomers want to use to study the objects in various ways.

The information we have is what color the filter was and then we can reconstruct by putting together various images taken in different filters; images that vary in color composition.

Ultimately these are photographs. We use photographic techniques and techniques from art even because this is imaging information and aesthetic information. We use the same kinds of techniques that an art photographer would use to improve the pictures, to make them more interesting, to bring out details of the images that are in the data but may not be apparent on just looking at the data naively and various techniques to make the images visually, aesthetically look better.

We go to the next slide…

Frank Summers: Okay, before we move to the next slide any questions?

Nancy Ali: This is Nancy Ali from Windward Community College Imaginarium in Honolulu. I'm wondering if the color filters are the same across agencies. For example, do all scientists use the same color filter for a particular wavelength or does it just depend?

Zolt Levay: There are standard colors for the filters. There are roughly two kinds of filters. There are what are called broadband filters that sample a fairly large range of colors in the spectrum, and there are narrow band filters, which are intended to isolate a very narrow range of wavelengths. Those are usually associated with the emission of particular chemical elements.

Hydrogen shines in light in various very sharp color bands. The filters are tuned to match those specific colors of emission of those chemical elements.

Frank Summers: Let me just add that one great thing about standards is that they are standard but there are also so many standards to choose from. You can have the Johnson V band, you can have the Cousins V band, you can have the Chrome V band -- the various telescopes both in space and on the ground will get various filters but they might differ in which ones they choose.

A lot of what we do as astronomers… If there's an observation taken in one filter and we've got a slightly different filter, we have to do what we call a transfer function to say what that measurement corresponds to. The measurement in this filter is not always exactly the same as the measurement in that filter.

Zolt Levay: One of the great opportunities Hubble Space Telescope gives us is to image the sky better than we've ever been able to do before. With every opportunity comes a challenge, so I will also talk about some of the challenges that we face with the biggest telescope. As already I mentioned, we work the data that's available from the telescope; the observations are designed by

astronomers to do astronomy, not necessarily optimize to make the best pictures.

In general, we work with data that's in the archives, that's been made for scientific purposes. As it turns out, a lot of these data sets are really good for making nice pictures so it's not really a problem.

One issue is that the images represent a huge range of brightnesses. While these objects we're looking at are very faint on the sky, the power of the telescope and the instruments comes in being able to take this faint light and add it all together and come out with an image that represents the light that's coming from these objects.

In most astronomic logic the range and brightnesses from the brightest star in the same star field to the faintest star is a huge brightness difference, so much larger than you can represent on a computer display or on a print or in any medium you can think of.

Part of the task here is to take that great brightness range and somehow massage it into this relatively limited range of physical representation of an image that we can have.

Another issue that we deal with is spatial coverage on the sky. Hubble's field of view is fairly small and so many of the objects fit neatly into the field of view but others are, you know, we can only cover a fairly small part of it. Either the image is cropped down or in some cases we've been able to make mosaics - build up a larger image from multiple fields of view and build up a large mosaic of a larger region of the sky.

Then there's the issue of spectral coverage. Hubble can see light that our eyes can't see and a little bit into the infrared and a little bit into the ultraviolet. But there are some limitations and with the filters, the selection of filters they may not match our visual perception, what our eyes perceive in terms of color.

In a lot of the cases the color that ends up in the final image that's a reconstructed color image may not match what we would see with our eyes. There are issues of spectral coverage.

And finally, the word, 'cosmetics,' which means that there are blemishes in the image -- things the instruments put into the image that aren't really part of the object that we're looking at and other issues like that. We take care of those cosmetically to make them more pleasing, more aesthetically attractive imagines.

It's not a problem. Tt's just standard stuff that any photographer would do like taking out a dust speck from your negative, although we don't deal with negatives anymore.

Frank Summers: Any questions on this?

Randy Bond: This is Randy from Salt Lake. How can you determine if what you are seeing is actually a flaw in the optics?

Zolt Levay: There are standard kinds of things and I'm going to go through some of those near the end of the presentation.

In fact, it's actually kind of a good segue, unless somebody has another question I think I'll defer that kind of to later. If I don't answer it you can ask again.

Frank Summers: Moving on to Slide 6.

Zolt Levay: The next slide. When I showed the first black and white picture and said this is what raw data looks like, I kind of lied. This is more like what raw data looks like. The biggest thing you notice is this planetary nebula NGC 6369, which is different from the object in the first picture. It has a sort of salty look of very sharp dots all over the image.

These are not part of the object we're looking at; these are the result of cosmic rays, those energetic particles that are all over through space and hit the detector just like the light does and make a detection on the camera.

It's kind of unfortunate because it kind of messes up the image.

Zolt Levay: Like I said, this is more like what a single frame from the Hubble Space Telescope looks like; every picture from Hubble has these cosmic rays on it. But you actually don't see the cosmic rays in the final images. And it's kind of a neat trick, if we go to the next slide…

Frank Summers: Slide 7.

Zolt Levay: …we have another image of the same object taken with the telescope pointed precisely identically. If you can flip back and forth between them you'll notice that the planetary nebula stays the same but all these little cosmic rays jump around a little bit.

The cosmic rays come in randomly and they're distributed randomly on the exposure. This is a good thing actually because what you can do is

mathematically combine the two exposures and take the good stuff from each image and throw away the bad stuff.

If we look at the next slide, Slide 8…

Frank Summers: Slide 8.

Zolt Levay: …we see that the cosmic rays have magically disappeared. It's kind of a neat technique that we can get rid of a lot of these cosmetic blemishes initially. You can see other things on there but I will, again, defer that to a later discussion near the end.

This gives you the picture that showed you what the data really looked like, and it also gives you a flavor of the kinds of processing that happen with all of the data -- not just the data for making pretty pictures but also the data the scientists get because the scientists don't want to deal with cosmic rays either.

That's why they do things like take multiple exposures so they can remove the cosmic rays from their data. It gets in the way of measuring things like brightness of stars and so forth if you have all these bright dots on your image. Plus there are standard processing techniques that go on with all the data.

Frank Summers: Let me just emphasize what Zolt said. As a scientist, I would do the exact same thing if I were an observer – I'm a theorist instead. But, He's not doing something for the press release images that doesn't get done for the same images that appear in the astrophysical journals.

Zolt Levay: At least up until this point.

Now let's go to the next slide.

Frank Summers: Before we go on, any questions on cosmic ray subtraction?

Okay, Slide 9.

Zolt Levay: I guess, maybe I lied again.

Frank Summers: I knew you were going to say that. It was just coming up.

Zolt Levay: Maybe it really wasn't what they really look like. It depends on how you render the data; it depends on how you look at the data. If we naively display an image out of the archives, this is often what you get -- this sort of blank looking field with maybe some hints of some stars in it.

This is because if you display the entire range of brightnesses that's represented by this image, most of it's going to be dark; it's going to be a dark sky with a few spikes or relatively bright stars.

However, being digital data we can easily manipulate it and look at this in a slightly different way. If we go to the next slide we've now brightened this image and now we're seeing all this nebulosity there; there's some stuff that's not just stars and the stars are brightened enormously.

Now the brightest things in the picture are stars and then there is some relatively faint nebulosity that shows up.

And so if we go on to the next slide…

Frank Summers: Slide 11.

Zolt Levay: …we brightened it even more and see, oh, there's even fainter nebulosity that I can see in this image if we keep cranking up the brightness. Unfortunately now we've made it so bright that a lot of the brighter parts of the nebula are totally white and saturated, as we say, and there's no detail there.

Fortunately since it's a number, we can work with the numbers and if we go onto the next one…

Frank Summers: Slide 12.

Zolt Levay: …slide 12 we've now applied a functional relationship between the numbers in the image and the brightness at which they're represented in the display. We're able to transform this image so that we see detail everywhere in the image from the brightest parts of the nebulosity, and we've even brought out even fainter nebulae in the darkest parts of the image.

Now the stars are saturated. There's nothing much we can do about that. There's no detail in the image of a star; they're always inherently pinpoint. We don't care that they're saturated. But I like to see detail in the nebulae so this is what we've done.

This gives you a flavor of the kinds of things we can do routinely to enhance the images in a pretty straightforward way.

Frank Summers: Now we would call this nonlinear stretch; what would the Photoshop users call it? Is that what they call it?

Zolt Levay:	Yeah, an intensity scaling or a curves adjustment. In Photoshop you can even get more sophisticated because you can have an arbitrary contrast adjustment on the image so you can really play with it in great and gory detail.
	This is what we do later on down the road - and in fact do it in Photoshop. You can enhance the contrast and the brightness of any area independently, just like a photographer. If you're familiar with photographic technique, the terms dodging and burning and the old chemical darkroom, you could brighten or darken or change the contrast in different parts of the picture independently so you can maximize the contrast throughout the whole thing.
Man:	Are you adjusting the histogram here?
Zolt Levay:	Yeah, the result is that the histogram changes; we're changing the transfer function between the numbers that represent the image and the brightness that they're represented at. In this case in particular it's a logarithmic function that is used in the transfer.
Frank Summers:	Logarithmic function would be something like: if it's 10 times bright you could map that to be 10 times the number. In the data it would only map to be maybe twice as bright.
Zolt Levay:	Right.
Frank Summers:	All right, until if it's 100 times as bright in the number it would only be four times… something like that?
Zolt Levay:	Right. What that does is it compresses the brightness range so that very large ranges in numerical value in the image translate into smaller brightness differences in the represented image.
Frank Summers:	Any other questions on this?
Man:	You're normalizing the data then, right?
Zolt Levay:	Yes, in a sense.
Frank Summers:	All right, Slide 13.
Zolt Levay:	Another issue is what part of the star we are looking at and our field of view and so forth. This is a representation of a piece of the sky around the famous Carina Nebula; Eta Carina is the brightest star in the center of the image. And the blue boxes are fields of view of Hubble images with the ACS camera that were made in a large mosaic, large for Hubble, mosaic of this part of the sky.

A single exposure with ACS is actually a pair of these rectangular boxes ends up being a square region of the sky – a little complicated but end result is that we have a reasonably large mosaic of fields of view on the sky and we can map out this area.

If we look at the next slide…

Frank Summers: Before you go on… This looks likes it's about 30 or so images with ACS; is that true?

Zolt Levay: It's actually 48 overlapping fields, but they overlap about 50%. So it ends up being 4 by 8 pointing mosaics.

Frank Summers: Each one of those, of course, is 16 megapixels.

Zolt Levay: That's right.

Frank Summers: This is a lot of data, folks.

Zolt Levay: We're talking a lot of pixels.

Frank Summers: All right, moving on to 14.

Zolt Levay: This is what it ends up looking like, the individual Hubble ACS images. Each square represents a separate exposure – well actually two exposures as we described with the cutting of the cosmic rays; so each of those two exposures has been combined.

We have 48 – 96 individual exposures, 48 separate places the telescope pointed and it's stretched out a little bit because they overlap a great deal. I might add that the black bar going through every image results because the camera is actually two separate detectors - two separate cameras.

Unfortunately they don't overlap in the camera; there's a little bit of a gap between them just for physical reasons they could not make the camera such that the two detectors butt up against each other exactly.

If we go to the next slide…

Frank Summers: Slide 15.

Zolt Levay: …the images have been registered how they overlap with each other on the sky. This is the mosaic image as it appears. There's still some gaps in there from the gaps between the detector chips that, unfortunately, the observations

were designed such that they did not overlap over those missing gaps but that's not too much of a big deal.

Again, going back to these instrumental artifacts I'll point out a couple of things here that the brightest place in the image off to the left third of the image in the middle is Eta Carina this very, very bright – one of the most massive stars known.

It's so bright that it's really over-saturated in the detector and it's saturated so much that it has this long 'bleeding' through the detector and kind of a nasty thing. That's one of those instrumental artifacts that's obviously really part of the object on the sky.

If you look at some of the fainter stars they also have these streaks going through them that are these bleeding artifacts. We have ways to get rid of those.

If we go to the next slide…

Frank Summers: Okay, Slide 16.

Zolt Levay: The previous one has been scaled for the data range. It's been mathematically scaled to show the optimal range of brightness without saturating anymore than we have to.

This one has been adjusted in Photoshop with local contrast and brightness adjustments to really bring out all the contrast and brightness that we possibly can in this image. If you flip back and forth between the two – if you go back to slide 15, you see it's kind of flat and there's not much detail visible.

If you go to the slide 16, it really pops out and a lot of the details really show up just because we've gone in and adjusted the brightness locally within the image. You can't go back and try to do measurements on this image anymore; at this point it's kind of gone from being data to being a picture.

We've used some subjective techniques to enhance the image and make a more appealing image and bring out details that are inherent in the data. I wouldn't advise anyone to make any brightness measurements on the image because they're going to be way off.

Man: When you say, "local enhancements," you're going with a select tool and selecting certain regions and then doing enhancements on just those selections regions?

Zolt Levay: That's right.

Man:	I'm just wondering, how many pixels is this because at 48 16-megapixel images you're up at hundreds of megapixels.
Zolt Levay:	It's about 400 megapixels at this point.
Man:	That strains most any computer you've got, right?
Zolt Levay:	It's a challenge especially since we're doing this 16-depth view -- kind of like working on raw format images out of a high-end digital camera.
Frank Summers:	Move on to 17.
Zolt Levay:	Finally we get to the color, which is probably the thing that everybody wants to know about. How do we get the color images done? This is an example where we have an image taken through three different colored filters. The letters are the coding for the filters; we have an I band filter, which is in the red to near infrared part of the spectrum; a V band image which is the middle of the yellow part of the spectrum; and a B band image, which is in blue.

If you look at the images you can tell that there are some differences there but it's not real obvious; the blue has more structure and contrast in the galaxy and the red is smoother.

We take these black and white images and apply a color to them, the color that is appropriate for the filter we used. If we go to the next slide we have now applied red color to the I band filter – to the reddest filter, a blue color to the B band filter, the bluest filter, and a green color to the intermediate V band filter.

These colors that we've applied don't necessarily match precisely the color of the filter but the reason we use these colors is because every color reproduction process is a three-color model and these three colors, pure red, pure green and pure blue are the primary colors in an additive color model like we're using here.

With these three colors you can reproduce every color essentially that we can see with our eyes and it gives you the broadest range of colors when they combine together. The different colors in different proportions combine together and produce all the intermediate colors that we can see.

If we go to the next slide, Slide 19, we see the results. We've combined all these colorized pictures together and now you see lots of different colors on the image from black to white and through the various colors.

For example, the two bright stars there in the sort of right third of the image, one is bluer and one is redder. If you go back to the individual images you can see that the upper left star is brighter in the blue image and dimmer in the red image. The lower right star is brighter in the red image and dimmer in the blue image. You can see where those colors are and their correspondents there.

You can see that there's a fairly broad range of colors in that image. There's nothing really magic about it; that's just the way the colors are reproduced. Every color reproduction technology uses a three-color model to produce colors. That's the basis of it.

Frank Summers: Zolt, these aren't exactly matched to the RGB that we think of for televisions or other red/green/blue filters that we might think of, is it? Because the I band is a little bit closer to red than you would…

Zolt Levay: The filters in the camera are not matched to the red/green/blue pure primary. We map whatever the color of the filters are, and these three filters aren't necessarily always the ones that we have. There's a whole range of filters and the camera is designed to do astronomy not designed to make color pictures.

For various reasons scientists will choose various filters, and they may not map to the colors that we use to represent them. For example, they may use a red filter or a yellow filter and a green filter, so we can still map those to the three primaries, red, green and blue.

It not only produces a more pleasing picture with the full range of hues but also kind of stretches out that color in a sense because in some cases the filters may actually be very close to each other in color but because they're picking out different physical processes going on in these objects that we're looking at. Whether galaxies or nebulae or stars, they are actually going to select out different physical conditions so there can be dramatically different images.

This is a good segue to the next slide…

Frank Summers: Let me just make one more point because this one's pretty much what the human eye might see if you could have eyes as big as Hubble and exposed for many hours etcetera, although no image from Hubble is ever really truly going to be what the human eye can see.

Zolt Levay: No, there really isn't that one-to-one correspondence but an image like this is closer to what we would see. It's also stretched because of the contrast enhancements that we've done on the individual gray scale images and in the further processing the color has been strengthened.

That's probably a by-product of all this process but also intentional to bring out these colors more and to show the red stuff is significant and the blue stuff is significant. The blue stuff is showing where stars are being formed, young, hot little stars. And the red stuff is older, fainter stars or dust reddened material. There really is something to be seen by stretching out these colors a little bit.

Frank Summers: All right, let's move on to Slide 20.

Zolt Levay: This is a slightly different example. Rather than the broad band filters that we saw before, which are more like what our eyes do sampling broad chunks of the spectrum in these different color filters, we're really picking out very specific wavelengths of light with these narrow band filters.

The wavelengths of the filters are matched to emission of specific elements and specific physical conditions. In this case we've taken images of a planetary nebula in three different narrow band filters; one on the left in the light of ionized nitrogen atoms; and in the middle there's an image taken in the light of hydrogen and on the right is an image taken in the light of ionized oxygen.

The colors or the words there, red, red and cyan, are close to what the colors of the filters are. So the nitrogen filter is in the red part of the spectrum, the hydrogen filter is also in the red part of the spectrum, actually very close to the nitrogen line and the oxygen emission in the blue part of the spectrum or the blue-green part of the spectrum, cyan.

If we now do the same thing with these images, assign the colors to essentially what the colors of the filters are – if we go to the next slide – we make the nitrogen image red, the hydrogen image red and the oxygen image cyan.

The other thing I wanted to say was that even though the nitrogen and the hydrogen image are very close in wavelengths, you notice that the images are really significantly different. The structures are different because the emission is coming from different physical conditions in this nebula whether it's temperature, density or whatever, energy level. Essentially, they're coming from different places. The emission is coming from different places in the nebula or different physical conditions. The images end up being very different even though the wavelengths are very similar.

This gives you an idea of what the astronomers are looking for when they're using these particular filters to pick out these chemical signatures.

John Stoke: Hey, Zolt? It's John Stoke. One other thing worth mentioning is that these filters pick one spectral line out of many that are emitted by any given element. So it's not as though the hydrogen was a monochromatic red, the actual hydrogen gas you looked at it emitting its light and it looked more pinkish.

Zolt Levay: It's all kinds of physical conditions. People sometimes that's all where the hydrogen is and that's where the nitrogen lives.

                   All these elements are in these nebulae all mixed up together. It's really what we're picking out is the physical conditions in the nebula.

:   The excitation level, the energy level that's in these particular regions of the nebula, each element is in this light and all across the whole spectrum.

Frank Summers: Slide 22.

Zolt Levay: If we assign the colors of the filters to the individual black and white images and then combine them like we did before, this is what we end up with, which is kind of an interesting picture but it's also kind of monochromatic.

                   If we do it a little bit differently -- instead of assigning the colors of the filters we assign our additive primaries red, green and blue to the three images and we go to the next slide…

Frank Summers: Slide 23.

Zolt Levay: Now we've assigned red to the nitrogen, green to the hydrogen and blue to the oxygen – a deeper blue, a spectral blue, rather than cyan. Then we go to the next slide, Slide 24. As a result you see quite a different image. You see the same structure but there's much more color separation; there's much more color range in the image because we've used all three primary colors.

                   I think of it in two ways: it's stretching the color out and you're able to represent more of what's going on in this object. There's also a distillation of the color and distillation of what physical processes that are going on in this image.

                   While it's technically unreal color, we would definitely not see it this way with our eyes; it really brings out more of what's inherent in the data than we would see otherwise. That's really the whole point of these images is bringing out as much as we possibly can of the detail that's in the data.

Frank Summers: Any questions on this?

I have one more comment. In just looking at this there's the streaky things around the outside of the Epsilon Nebula, the things that look like whiskers pointing off in all directions; we call those "cometary knots," this is a planetary nebula.

What strikes me here is that you'll notice that the heads of the cometary knots are yellowish where as the tails are golden-brownish. That seems to indicate that just looking at it like this that the heads are the hotter part, the ones that are being hit by the wind from this planetary nebula, whereas the tails are cooler and are more in the nitrogen than in the hydrogen line.

That's something I hadn't really noticed about this image before but as we're sitting here looking at it that strikes me that you've got this yellow inner-fringe and a browner outer-fringe part of the Epsilon.

Zolt Levay: That's actually the kind of thing that people can do with these images. You can't obviously do measurements on them because we change the scaling and contrast levels and so forth. But qualitatively people can look at them and since our eyes are more sensitive to small variations in color than they are to small variations in gray level than sometimes it's easier to pick out these features like Frank was talking about, in the color composites than it is in just looking at the individual images by themselves.

Frank Summers: Let's move on to Slide 25.

Zolt Levay: Now I'll talk a little bit more about what we do with these artifacts and retouching and things. These are kind of things that a photographer would do to fix up their image. I'm not saying we're honing out things that aren't there or honing in things that aren't supposed to be there.

But the kinds of things are instrumental artifacts, backgrounds that are uneven for various reasons and noise. If you're familiar with digital photography at all, one of the banes of digital photography is noise in either when you take very long exposures or in very dim light you get this uneven texture in the darkest parts of the image that's caused by just the fundamental nature of the way the images are made.

Finally, I'll say a few words about sharpening and things like that at the end.

If we go on to the next slide, here's an image of the Sombrero Galaxy. If you notice in the lower right of the image there's a bright star there. And if we go to the next slide we'll zoom up on this star. And you notice that it has a few features. One thing is the perpendicular diffraction spikes that are going through the image, which are caused by the structure in the telescope that's

scattering light inside of the telescope and causing these diffraction spikes, which you get with every telescope.

It's an artifact but we don't get rid of them. I guess it's a little bit glib but a lot of people think that stars should have diffraction spikes. We don't get rid of the diffraction spikes because people expect the…

Man: How come it's not a five-pointed star? I always thought that stars were five-pointed.

Man: Six.

Man: Six; six-pointed, okay, I'm sorry.

Zolt Levay: Well, our stars are four-pointed because there are four vanes holding up the secondary mirror in the telescope. That's where the four-pointed stars come in.

The other artifact is this horizontal line that's going through the star that's longer on the right side and shorter on the left side; it's offset a little bit from the diffraction spikes. We do want to get rid of that CCD bleeding.

One kind of clever little technique is related to our cosmic ray removal technique; we can replicate the image – if we go to the next slide – we've replicated a piece of the image and then rotated it 90 degrees. Now our diffraction spike is vertical instead of horizontal. If we now erase everything that's in the image on top except for where the diffraction spike is underneath…

Frank Summers: Are you talking about the bleed?

Zolt Levay: Yeah, the bleed, not the diffraction spike, the bleed. Then we can replace good stuff from the image and replace the bad stuff with good stuff. Then we end up with this – as we look at Slide 29, a cleaner version of the image.

Again we've put stuff there that wasn't there before but all that radial structure in the star is scattering light in the telescope and the instrument. It's not obvious stars are pinpoints. We're not really doing anything untoward, just cleaning up the image.

That's one technique; this is just an example of the kinds of techniques that we use to make the images more appealing.

Frank Summers: Slide 30.

Zolt Levay:	Here's one of our deep fields; this is actually the good deep field and Great Observatories Origin Deep Survey, a large mosaic of fairly deep images. This is what the sky looks like everywhere. What we're looking at is galaxies of course.

If we brighten this image considerably and look at the next slide, you'll notice that the background is pretty uneven. We have these bars going through it. This was because this image is a mosaic of multiple overlapping fields and there are different levels of exposure where the images overlap or don't overlap or multiple images overlap.

Some parts are a little less noisy; some parts are noisier. Much of what you see is noise. |
Man:	This is the exact same image just with a stretch change? If I flip back to the other image and I really looked carefully I might be able to see these artifacts? The artifacts are in the other image but they're just brought out here?
Zolt Levay:	Yes.
Man:	That's cool.
Zolt Levay:	It's cranked up the brightness. And you notice that the brighter galaxies are now saturated and formless in the brighter version but we do see these artifacts in the background.

We go in and manually adjust the color and brightness of these regions so they kind of match better. It just cleans up the image. If we look at Slide 32 now… Again, it's the brightened version, cleaned up. It's not completely gone but it's much better.

If we go back to the normal brightness then it will be just a cleaner image with a cleaner background. Again, giving you the flavor of the kinds of things we might do to clean up an image. |
| Man: | That doesn't look like it's an automated procedure? |
| Zolt Levay: | That's definitely not an automated – now there are some automated things you can do, or semi-automated things, but this is the way I do it. It is a lot of hand retouching in Photoshop. It's using a lot of math and curves adjustments and things like that.

Often, when you change the brightness you change the color so you've got to tweak the color a little bit back to where it's supposed to be. It is a manual, tedious manual process especially for larger images. |

Frank Summers: All right, moving to Slide 33.

Zolt Levay: We use standard techniques from art and photography to try to make the images more appealing. The kinds of things we think about are the overall color, how colors relate to each other, the forms that you see in the image and the textures that you see just like you'd think about making a nice composition with a photograph.

In terms of composition how you crop the image, how you orient the image, how you rotate it a little bit. Perspective maybe not so much; we don't have any control over the perspective. But perspective in terms of how different objects in the image relate to each other, the size of the various objects, how you might crop and rotate – select which part of the image you want to show.

Finally, lighting and tonality; we don't have any control of the lighting of the subjects we're looking at but we can select certain subjects or crop them in a certain way. The example that comes to mind is the old Eagle Nebula image, Pillars of Creation image, which owed it's grandeur in many ways to the fact that this is a real physical object that's being lit in a certain way, almost a studio lighting kind of way, strong backlighting and highlighting the three-dimensional nature of the image.

Those are the kinds of issues that go through your mind when you're thinking about how you might work with an image and make it a more appealing image. Some specific examples, if we go on to the next slide…

Frank Summers: Slide 34.

Zolt Levay: In terms of composition this is an image that has a funny shape because it was a mosaic of half a dozen or so different images that were not taken to make a pretty picture but taken to do certain science and look at certain places in this, the Triffid Nebula.

It has a funny shape, which wasn't really very appealing to me. One way we can deal with this is just to crop out a rectangular section. If we go to the next slide, I've drawn out the largest rectangle that I could at a nice angle to show as much of this thing as possible.

Obviously, we're going to get rid of a lot of interesting looking stuff but them's the breaks, the decision whether you want to show this kind of raggedy edged thing or you want to show a nice rectangular picture that may highlight certain interesting regions of the image.

If we go to the next slide that shows what the cropped image looks like and we see the flavor of the kinds of thoughts that go through and how to improve the look of an image overall.

Frank Summers: All right. Next. Slide 37.

Zolt Levay: I think that's the last one; I just tried to summarize a little bit kind of the ideas that I was trying to emphasize here that we're working with science data here - data from the Hubble Space Telescope. As a by-product of the science we can actually make some nice looking pictures.

That I hope convey some of the technical things we're looking at in the image but also, in a more emotional way, convey the grandeur of what we're looking at and the awe that I feel when I look at these images. I want to convey that to everyone else, and I hope that everything we do to these images helps to make that possible -- that other people have the same feelings when they look at these pictures.

We use standard kind of photography techniques to do this work. There are some subjective choices, so you can't claim that this is objective science here but the subjective choices are informed by what's inherently in the data. We try to part with as little as possible from what's actually in the image data.

It's been formed by, but also informed by, principles from the art world on how to convey images in the strongest way possible.

The bottom line to me is that this is nature photography. It's not Earth-bound nature photography but it's cosmic nature photography. We're using art photography techniques to make the universe come to everyone.

Frank Summers: All right. Thank you, Zolt. Everybody give him a nice round of applause.

Any questions for Zolt now at the end and anything in the talk or other is fair game for him.

Man: The question I'd like to throw out is: a couple times been asked things like, "Is this what these things actually would look like if you'd view them through incredibly powerful telescopes?" It sounds like the answer to that question should be, "no."

Zolt Levay: The answer is generally no; there are a few things, most notably the things that we have some so-called ground truth on, things like the solar system objects, solar system objects generally are pretty accurate.

Frank Summers: Like Mars. You try to get Mars looking pretty much…

Zolt Levay: We did try to do those so that they looked like what they're supposed to look like.

               These other things in general… First of all, they're so faint that even looking through the Hubble if you could you still wouldn't see them because it depends on this large integration time, building up the image within the instrument and then the selection of filters just throws everything out of kilter.

               You could do it in general; things would look rather pale and colorless.

               In general the answer is, "no, these things are not what they would look like if we could see them with our eyes."

John Stoke: I'd just like to comment on that just for a minute because that's a question that anybody who gives talks receives a lot. I think, obviously to say, "no, this is not what your eyes would see," is something that should be said because it's true.

               This gives a great introduction. It's a teachable moment about what the purpose of telescopes is and the purpose of telescopes is to enable us to see what we can't see with the human eye.

               The first couple of centuries of telescopes the human eye remained the detector because that's all we had. We could gather more light and we could get a narrower field of view and thus see more detail in the sky. But we were still dependant on the human eye, which is an extremely flawed detector in many ways; it's - pick your metaphysics - designed or evolved for the purpose of looking at objects on the Earth that are reflecting broadband sunlight, it's not designed to look at the kind of phenomena that exists in the Universe.

               With the improvement of detectors, we can reveal a lot more. The bottom line of the techniques that Zolt's talked about is that it's designed to extract the most amount of information that's possible to display in the given medium. Generally aesthetic appeal and information content go hand in hand; a picture of a fog is generally not interesting, not very aesthetically interesting.

Man: Tell that to Monet.

John Stoke: The other thing to remember is that the human eye is not the measure of what things look like, it's what things look like to the human eye. We know that honey bees have a very different impression of what flowers look like, for example, in the ultraviolet than the human eyes do.

Steve Fentress:	Steve Fentress in Rochester, New York. I had a question about the registration process a few slides back particularly the one with the 48 overlapping fields.
	Do some of you have consumer experience with the panorama making software with our cheap digital cameras? That can sometimes be a pretty slow process. On the other hand the cameras don't have necessarily top quality lenses. Is the registration process hard with these when you get that many of them? And how do you do it?
Zolt Levay:	It is hard. In this particular case I registered those by hand in Photoshop, each image individually. There is software to help with that specifically designed for these images. But there are complications when you have a wide field like that. I'm not an expert at using that software. For various reasons it was more convenient at the time to register these by hand, but there is more automated software.
Frank Summers:	You're talking about multi-drizzle, right?
Zolt Levay:	Yeah, it's called, 'multi-drizzle.'
Frank Summers:	Multi-drizzle operates on the FITS files, the basic raw data that comes down from Hubble -- flexible image transport systems, FITS files. Multi-drizzle was written by an astronomer here at Space Telescope and it's been developed over many years to really work on those things.
	It's available if you want to work with FITS files and such. But it seems like Zolt has done it.
Zolt Levay:	In principle, once you get the images in a format like a tiff or a jpeg, you could run them through one of those panoramic softwares. In principle it ought to stitch them together.
	In fact, Photoshop now includes that capability; it's not quite as sophisticated as some of the dedicated panoramic stitching software but it's quite useful. In fact I've used it in some cases to simply register images on top of each other where there might be a slight rotation or something. There's lots of ways to do that.
Tom Hill:	This is Tom Hill from Maryland. I heard all the arguments about the colorizing of the images and extracts more information but how do you deal with the disappointment that somebody has when they look through a Nebula in their own telescope and it doesn't look that way? Has anybody come up with a good response to that?

Frank Summers: How much did their telescope cost and how much does Hubble cost? If they can see it through their backyard telescope, we really overpaid for Hubble.

Zolt Levay: I think John Stoke actually answered that question in saying that their eyes aren't really good detectors. And the detector, whether it's a photographic detector or a CPD or the very, very high end detectors that we are fortunate enough to have on Hubble and other special telescopes, their just much more designed to do that and our eyes aren't designed to do that.

For one thing our eyes don't integrate; our eyes are instantaneous detectors so that whatever you can see from one 30th of a second to the next 30th of a second is all the light that your eyes will gather.

An imaging detector builds up an image over, it could be hours or days in the case of some Hubble images like the ultra-deep field it was more than a week's worth of…

Frank Summers: Eleven days aggregate from all the images.

Zolt Levay: That's millions of time more light just in terms of time, than your eyes can see instantaneously. Tthe real answer is that our eyes aren't really very good detectors.

Steve Fentress: I think I'll go with the eyes answer instead of the how much did you pay for your telescope.

Zolt Levay: Great, thank you. They go hand in hand, I guess.

Frank Summers: They do sort of go hand in hand, yeah.

Zolt Levay: You get what you pay for.

Frank Summers: I have a question that you didn't cover. In the Eta Carina Nebula you've showed what an incredible detector bleed we had, but you didn't say how you got rid of that as well as the chip gaps.

Zolt Levay: There are two things there: the chip gaps – well, actually it's a little bit more complicated – the Hubble data for that image was only in one filter, it's only in hydrogen analysis data. There is a color image of that; the color comes actually from ground-base data. It turns out that we can combine the very high resolution Hubble data with lower spatial resolution color image data and you end up with a color image that has all the spatial resolution of the full resolution Hubble data but is a color image.

Along with that we used the ground-based data to fill in the cracks, those missing pieces of data in the vertical bars that were left from the chip gaps. That's one side of it.

The other side of it is the bright star, which was totally saturated in the Hubble data. We actually used other Hubble data - shorter exposures that were not saturated and just filled them in, registered images, different short exposures that were all combined together to produce a nice clean image.

It's a lot of hand work to stitch all that data together. But it's like if you were to take a group portrait and somebody had their eyes closed. You take more than one picture and swap in the head with the eyes open from the head where the eyes were closed. I've done the same thing before, which is kind of fun.

Frank Summers: Any last questions for Zolt?

All right, folks, Kay, thank you very much for running the phone call. I know Anita wanted to be here but she couldn't. Next month will be on April 3; it will be a Hubble Science Briefing, and Anita said she had somebody she wanted to speak next month. I can't remember exactly who it is. If she doesn't arrange for him to speak, I will grab an astronomer around here or even fill in myself if absolutely necessary. But we will have another Science Briefing every month on the first Thursday of the month.

Thank you all for coming and have a great month. Bye, bye.

<div align="center">END</div>