Dave Eicher: Well welcome to the first ever Super Stars of Astronomy podcast from *Astronomy* magazine. I'm Dave Eicher, editor in chief of *Astronomy* and I want to thank Celestron, manufacturer of superb telescopes, for generously sponsoring this podcast series.

Each month I'll be sharing the thoughts and research of the world's greatest astronomers, astrophysicists, cosmologists and planetary scientists with you in these hour-long chats.

I'm very excited to have a wonderful and special guest for our first show in Jeff Hester. Jeff is professor emeritus at Arizona State University. These days he is working as a professional coach and speaker, sharing his experiences and perspectives with individuals and organizations.

His website is jeff-hester.com, and I encourage you to check it out.

Jeff is extremely well-known for a wide body of scientific research and is the one who made the most famous-ever image with the Hubble space telescope, the celebrated Pillars of Creation shot of the Eagle Nebula M16.

And let me just say Jeff you're not only one of the smartest people I know but you're also one of the wisest, and that really became clear to me many years ago when I first got to know you so it's really an honor to have you here as the first guest in this series.

Jeff Hester: Well Dave it is a real pleasure to be here, and while I appreciate the compliment I don't know if I'm going to plead guilty to wise or not. I might actually be guilty instead to curious.

Dave Eicher: Well, that curiosity is a good thing unless you're a cat I think, but it is a very good thing for science.

Jeff Hester: Indeed, indeed.

Dave Eicher: Well Jeff, we have a lot of ground to cover here because we want to talk in really broad terms about lots of things that are going on in terms of our discovery of things in the universe in this hour.

But before we get started on that why don't we talk a little bit about your background. How did you get interested in astronomy and astrophysics to begin with?

Jeff Hester: I actually got interested in this kind of stuff when I was a very young kid. I grew up during the space race and so among my very

earliest memories were watching them put Mercury astronauts into the capsule and bolt them in and all of that.

Then I really got into astronomy in a way that I think a lot of your readers and listeners will understand: I was an amateur astronomer. I still remember the first time I went over to a friend's house and looked at the rings of Saturn through a little dime store telescope, and he and I then did a lot together — built some telescopes together, did astrophotography — and then when I went off to college my intention was to go into physics — I don't know, I was probably thinking about particle physics or something — but just because of my interest I took all of the astronomy I could get my hands on and pretty soon I realized that really what I had done was trained myself to go to astronomy and astrophysics.

So it was kind of starting out with an avocation — a passion for amateur astronomy — and that just kind of became what I did with my life.

Dave Eicher: Well, and I think that gives you a great appreciation of not only the beauty of the sky but also the complexity of everything that's out there, and that's really transformed into a very deep intellectual voyage of discovery for you.

You're very well-known for that Pillars of Creation shot and your study of the Eagle Nebula — of dark nebulosity, condensing gravitationally into stars and of giving us that view of stars in the 1990s.

Talk about, if you would about your work with the Hubble Space Telescope because you're one of the very best known users of the greatest astronomical telescope ever built.

Jeff Hester: Well, I have to start with a story. Some years ago I was at a party and a mutual acquaintance and a friend who was an amateur astronomer, and he said, "Oh, you ought to go talk to Hester on that stuff." And this guy came up to me and introduced himself and said, "I understand you have some interest in astronomy," and I said, "Yeah, I have some passing interest in the subject."

And he started telling me about his telescope. And it was a very nice telescope — I remember it was a 10-inch Meade — and this was early in the days of computer controls and that kind of stuff — and I was being very appreciative.

But as he was describing it you could sort of see his chest rising and you know — and not quite looking down at his nose at me but almost — and finally he says, "OK, what telescope do you use?" And I said, "Well, mostly I use Hubble."

Dave Eicher: End of story, end of discussion.

Jeff Hester: It was, you know, this beautiful moment of just the — you know, you can probably picture it in your mind.

Anyway, I got involved — I was on the team that was responsible for the first camera that flew on Hubble — the Wide-Field Planetary Camera — and I went and worked on that team just fresh out of grad school — and I had the kind of dubious distinction of being the guy that was sitting behind the — well, in front of the NASA select TV cameras and a monitor looking at the very first images that came down from Hubble, when we kind of looked at it and said, "Uh, whoops."

So an image from Hubble that I don't talk about all that often is that very first light image that people looked at and said, "I don't think that's what we were expecting."

Dave Eicher: Well, what was it like Jeff — not to derail things here — but that was just a heart-rending — a shattering moment — and a shocking moment for everyone. No one suspected an optical flaw.

Jeff Hester: Oh man, it was a shattering moment. And in that moment you're not really entirely sure what to say. You look at it and it's just not right and of course this is the first time we've had anything like Hubble and so we didn't really know what was going on — although there had already been some inklings that there was funniness from the optical control system and things like that.

And it was really over the ensuing days and weeks that we started to really realize what had happened and then we realized not only that there was a problem but that there was really no way on orbit to fix the problem and then we really started realizing the impact it would have on the science, and so it was kind of a slow-motion dive off of a very, very deep precipice.

And when you finally hit bottom — I'm sure you're well-acquainted with the footage of the press conference when they announced all of this — and in fact when I talked to business audiences and such as that the picture that I use to say, "This is not who you want to be," is a picture from the press conference where

Ed Weiler has just said, "And, you know, I think we've lost all of that, and that's all." It was painful.

Dave Eicher: Things looked of course totally bleak and dark at that point, but then of course we had a triumphant servicing mission.

Jeff Hester: Yeah, after that — or fairly shortly after that I joined the team that was responsible for the Wide-Field Planetary Camera 2, which was the camera that fixed Hubble. You know, we account it for something like 65 or 70 percent of the science that was done after the first servicing mission.

And that project — you talk about working in a fishbowl, because we felt not only like we had the future of astronomy on our shoulders in a lot of respects, but we kind of felt like we had the future of big science on our shoulders in a lot of respects.

You know, we had been told that very, very clearly, and you know after the servicing mission, which was just an extraordinary — just a remarkable thing that carried on I guess for about a week-and-a-half and five spacewalks and all of that — and I remember the night — it was the very first image after the servicing mission came in and we were all standing around the monitor with baited breath and that image appeared and a shout went u. It was interesting though because that image — you know, the first time around we had had live — we were on live national television the first time around — and the second time around there were about maybe a dozen or a dozen-and-a-half of us down in the control room at Space Telescope [Science Institute], and there was one NASA cameraman that had a camera that was taking it all in, and I somehow suspect that if things had not gone well that footage never would have seen the light of day.

Dave Eicher: Yeah. But it turned out to be a transcendent moment and turned everything around, and although you had all the weight of the world on your shoulders it worked.

Jeff Hester: Well, it did. And it — I mean Hubble before it flew was counted as being kind of the biggest advance in astronomy since Galileo first pointed a telescope at the heavens, and yeah, OK, that was PR hyperbole and all of that but it was also kind of true.

The jump that Hubble represented in our ability to resolve structure, our ability to see things at great distance, our ability to do things like figure out the cosmic distance scale — all of those things —really were a game changer. And after the first servicing

mission, as the data started to come in and as we realized that we had — that the repair had worked as well as you could imagine that it would have worked — that we had essentially recovered 100 percent of the capability of the telescope — that realization that we were back — that after this incredible rollercoaster ride we were back to the point of delivering what it was that Lyman Spitzer had dreamed about all those years before.

And that kind of leads into the Eagle Nebula picture. Every now and then you're at the right place at the right time with the right thing to say. And the Eagle Nebula picture was taken a little over a year after the servicing mission, and so a bunch of very early and understandable public and political skepticism about, "Well is this really back, or is this all a spin job?" had pretty well faded — people understood that it was back for real: Jay Leno had stopped telling jokes on late night television. You know, he turned Hubble into a verb. If you had really screwed something up by the numbers you had *Hubbled* it according to Jay Leno. You know, "What sound does a space turkey make? Hubble, Hubble, Hubble."

So anyway about a year after the first servicing mission that image was taken and it was truly spectacular. You know we looked at it and straight away knew that we had something very special. And I showed the image to Ed Weiler and he said, "Wow." And then got a call back a little bit later from him saying, "You know, we want to do something special with this. We want to have a press conference. *Time* magazine is going to run a big multipage article on Space Telescope being back and we want all of that to feature this image."

And kind of through that process the Eagle Nebula image became the icon for Hubble in a lot of respects.

Dave Eicher: And one of the great icons for science and sort of, you know, as well as being a great shot of a well-known nebula that amateur astronomers know very well in the summer sky of course, it really sort of typifies — there's sort of a transcendent eerie look to the — you know, it sort of captures that human spirit of trying to understand the distant world and distant places in the cosmos that only Hubble had shown us to that degree.

Jeff Hester: Yeah, you look at it, and you'd almost think maybe you were looking at something organic on the bottom of the ocean. People just felt it.

And you know I heard from everybody. I heard from as many artists and musicians and people like that as much as scientists — to be perfectly honest. And the thing is that not only was it gorgeous but it was also a science story that people could wrap their heads around. You know, that if you could go back four-and-a-half billion years ago and watch our own Sun and solar system form, that's the kind of environment we formed in.

And in fact the evidence for that statement has gotten much, much stronger even since that image came out. We now know that the solar system formed in close proximity to massive stars in an area that was being shaped by the energy input from the stars, the radiation, the supernova — these things like that.

And so here's this gorgeous thing that people respond to, and they realize it has something to do with them — that what they're seeing here is not just a gorgeous thing off in the cosmos, but what they're seeing here is something that tells part of their own story.

And you know the response to it, not every astronomer has seen their work show up on a postage stamp or a *Time* magazine's *Collection of the 100 Most Influential Images in History* —

Dave Eicher: A pretty rarified air there.

Jeff Hester: That's pretty rarified air — and again, I attribute that mostly to just being in the right place at the right time with the right picture.

Dave Eicher: But it did ring — you're exactly right — I mean that's sort of the human quest for understanding: *Why are we here? Why are we here on this little planet? What is it all about? Where did I come from?* A lot of that, you know, if you understand what's behind that image gets answered in part in that picture.

Jeff Hester: Yeah, very much so. And you know this is kind of a really neat time in the history of the species in that respect. You know the idea that we can look at the universe, we can see the birth of the universe, we can see the evolution of galaxies, the evolution of large-scale structure, we can see new chemical elements coming into being, we can watch as stars form, we can see planetary systems forming around those stars — and that's just something that goes on out there all over the place.

And then you look at us and it's this extraordinary realization that we are sitting here and it's just the endpoint of that extraordinary process that we now understand — and not in the way — you

know, we're not talking about philosophically sitting around smoking funny weed and contemplating the number of angels that can sit on the head of a pin here. We're talking about a story that every step of the way it's hard science.

Dave Eicher: Yes.

Jeff Hester: And that's just a remarkable thing.

Dave Eicher: It's mainstream science. And you made a very important point: This is really a magical time to be alive and interested and aware of science because look at how — since the time of Hubble's launch — and not just because of Hubble but because of lots of other instruments and research projects — look at how the whole landscape of astrophysics, of cosmology, of planetary science has really changed in the last 10 to 20 years. It's phenomenal.

Jeff Hester: It is. In fact it's kind of funny because it's a — you know, I'm was a graduate student in the '80s, and we used to kind of joke that if you went back and read all of the various comments people like Minkowski [17:25] made at meetings and such as that, that yeah we wondered if there were any new ideas out there that those guys hadn't had.

Dave Eicher: Yeah.

Jeff Hester: What happened in the intervening few decades put that particular concern to rest very nicely.

Dave Eicher: We don't quite have it all figured out. I remember that book — I think it was *Cosmic Discovery* by Martin Harwit that I think came out in the '80s or the late '70s, and he sort of documented at the time that maybe something like 15 to 20 percent of the types of phenomena in the universe had been discovered up to that point.

Jeff Hester: And he was wildly optimistic to think that we had discovered that much.

Dave Eicher: Right.

Jeff Hester: I would love, for example, to be able to go back and talk to somebody like Fred Hoyle — and I don't know if your listeners know this or not but Fred Hoyle is the guy who named the Big Bang, and he didn't name it the Big Bang because he liked it —

Dave Eicher: Derisively.

Jeff Hester: The Big Bang was a pejorative name. He said, "You guys are all a bunch of idiots. You think the universe started in a big bang or something," and the name stuck.

And I met Hoyle once and he was a very interesting character. Later in life he kind of went off and did all manner of bizarre things. I actually met him at a time when he was talking about the ideas that interstellar dust were actually bacteria and — you know — but he was still a very, very brilliant man, and I would have loved to have been able to sit down with him and say, "OK, not only is the universe — that the universe began as a Big Bang and it's expanding, but that expansion is accelerating." And I would have just loved to have seen the look on his face if he had ever known about that particular part.

Dave Eicher: Never would have believed it. Never would have believed dark energy.

Jeff Hester: He never would have believed dark energy.

And it's an interesting thing too, I mean it — you know, when I talk to audiences about the nature of science the Big Bang and its naming actually makes a very powerful point, and that is we can sit here today and say that we know that we live in a universe that began in the Big Bang, and we don't say that because a bunch of scientists got together and tried to show that it was right.

We say that because an idea that nobody liked and everybody wanted to show was wrong turned out to withstand all of those challenges. So we don't know about the Big Bang because for the last 100 years people have been trying to show that, "Hey, let's make everybody believe there's a Big Bang." We know about the Big Bang because for the last 100 years people have been trying to show that there was no Big Bang and have failed miserably.

So that's how you really know things.

Dave Eicher: Yeah. And now we're living in a culture of the Net and blogs and a whole lot of nonsense in which the idea is that he or she who screams the loudest is the winner and that's getting, it seems to me, even farther and farther away from respecting and honoring the way science really works.

Jeff Hester: Yeah, it's kind of ironic that you know at a time when there is so much information available at our fingertips that knowledge itself

is becoming you know tenuous in ways that I don't think we imagined it would have been decades ago.

And there are a lot of things that contribute to that. One thing that contributes to it is that the Internet is the ultimate engine for confirmation bias. You know people like to hear that they're right. People naturally pay attention to things that they agree with and naturally ignore things that they don't. So what do people do on the Internet? Well, they go and find some group of people on bulletin boards or wherever who all agree with them and then they sit around and they tell each other how right they are and how wrong everybody else is.

Dave Eicher: Right.

Jeff Hester: And you know, you've got the Internet, you've got the Fox News' of the world — it's just a very strange time in that respect.

Dave Eicher: It is. Now Jeff you go and you give talks about the universe to groups of people and introduce them to what's going on and what our state of knowledge is, but you really go through a tremendously detailed roster of what we know about the cosmos.

And one of the things, of course, that strikes I think most groups that's amazing that they don't appreciate is the cosmic distance scale of just how vast the universe even very close to us is.

Jeff Hester: Yeah, that's one — it seems so obvious but at the same time not many people have really tried to wrap their guts around it.

You know, you look at the Earth, the Earth is huge but if you could travel at the speed of light you could circle the Earth in about a seventh of a second. That's about the snap of your fingers.

And so to use that as a yardstick where this planet upon which every human being was ever born was born and at the snap of your fingers you go to the Moon and it's about a second-and-a-quarter, you go to the Sun and it's about an eighth-and-a-third minutes, you circle the solar system itself and it's about a day. And so comparing the size of the solar system to the size of the Earth is like comparing a day to the snap of your fingers: and that's OK, you know what a day is.

To get to the nearest star now you're talking about a little over four years — or about the amount of time you spent as a high school or college student. To get to the center of our galaxy you're talking

about something like 28,000 years. 28,000 years ago our ancestors were Cro-Magnons living in caves in Europe.

Dave Eicher: Some of the dating Neanderthals too I think, huh?

Jeff Hester: Yeah, it's that time period.

And so when you talk about the scale of our galaxy compared to the Earth it is like comparing the age of modern man to a single snap of your fingers. And you're still only in the backyard. You want to go to Andromeda, now you're about two-and-a-half million years back — sort of back to the age of Australopithecine. You want to go to the center of the Virgo Cluster, now you're talking about 65 million years.

So when you look at the center of the Virgo Cluster — if you look at the galaxy — we're seeing them at about the time that the dinosaurs went extinct. And then you go all the way back and look at the cosmic background radiation itself, and now you're talking about a distance that's like two-and-a-half times — well, rather three-and-a-half times the age of our planet. And that's just kind of extraordinary to really try to wrap your head around that.

And it's kind of interesting because when you talk about that a lot of people sort of react by saying, "Man, I must be really insignificant." I actually think about that in a very different way. The way that I think about it is to say that in the midst of all of that here we are, able to actually look at it and think about it and comprehend it and understand ourselves in that context. And I think that is a very significant thing, not an insignificant thing at all.

Dave Eicher: Which is really extraordinary given the sentient being that can arise out of quarks and atoms and molecules on a planet like this, and that gets into all sorts of debate and opinion about how populated the universe is with life or with civilizations and all sorts of fun arguments and mostly bad television shows about how easy it is to travel around and shake hands with them all perhaps, right?

Jeff Hester: Oh indeed, indeed: lots of bad televisions shows, but hey, I grew up watching *Star Trek* too, so — you know even if they get a lot of that science wrong, they do an awful lot to kind of fan the flames of curiosity and passion to find the things.

Dave Eicher: Well, they certainly have inspired a generation of astronomy enthusiasts, no doubt about that.

Jeff Hester: They have indeed.

Yeah, and a remarkable thing about all of this too — you know, we talk about the cosmic distance scale and one of the things that's important to think about not only are the distances but the time.

You know, historians — if you're a historian, you're interested in the Civil War or something like that, you can go and visit battlefields, you can look at artifacts, you can get first-hand accounts; there's a lot that you can do to kind of understand it.

Astronomy, though, is the envy of historical science because we don't have to do that stuff: All we have to do is look. And the farther away we look, the farther back in time we are looking.

And so when we talk about what the early universe — you know, the very early universe — was like, we're not speculating or talking about something that was reconstructed after the fact: We're talking about the fact that we can look, we can see the cosmic background radiation and we can see the early universe.

You know, when you look at an image from WMAP [Wilkinson Microwave Anisotropy Probe] or something like that, you know, looking at the glow of the cosmic background radiation: you are seeing a baby picture of the universe — not metaphorically but literally: it's literally as if you were looking at a picture of a kid lying in a cradle. And so we can actually see what happened as the universe evolved. We can watch galaxies form, we can watch massive chemical elements come to be.

And a really remarkable thing — and this is back at that special moment thing — and there was recently a thing called *Illustrious Simulation* that was a brilliant illustration of this — if you go back and start a universe out the way that ours started — and we know it started that way because we can see it — and you say, "What will happen?" Well gravity will cause ripples in that early universe to grow, galaxies will form within those clumps, stars will form, nuclear fusion processes will produce more massive elements, those will be blasted out into space where they mix in with clouds so that when subsequent generations of stars form there's not just hydrogen and helium around but there's nitrogen and oxygen and carbon and then sulfur and all of that stuff that you need to do interesting things like build planets and people.

We can — you know, planets will form — and we'll wind up here talking about that — and all of that will happen for a very simple reason: It will happen because physics works. The fact that you can go back, start with the universe the way that we know it started out and turn physics loose and end up with the universe that we're in today is an extraordinary fact.

You know, that's why — and OK, I've done this for a long time, and there are times when I still sit around and kind of stare at the wall and say, "Wow," over that one.

Dave Eicher: That's really incredible. And where many people are used to reading about history, we can literally see history verifiably and know that physics is physics. We're not reading a book that has entire conversations between George Washington and someone somehow miraculously in it. This is the real story of the universe, and we're the real end result up to this moment in time of it.

Jeff Hester: That's right. And we know all of that again not because we've tried to build a house of cards but we know all of that because those ideas make testable predictions, and we can go out there and challenge them and hang onto the ideas that actually withstand that kind of scrutiny.

Yeah, science is a really extraordinary thing. And it is so poorly understood by so many people, but the idea that by refining your notion of what it is to know, that by saying, "Knowledge comes not from trying to show that things went right and succeeding," but rather, "Knowledge comes from trying to show that things went wrong and failing." That no idea is ever, you know, sacrosanct, no idea is ever free of further challenge.

You know, you'll hear people sometimes say, "Oh you scientists, you just have your theories. What do you know?" But the reality is is that a very well tested, very well corroborated scientific theory is the best that we as humans can ever claim in terms of knowledge of the world or anything else.

And the places that that has taken us — not only in astronomy — OK, *Astronomy* magazine, this is mostly what your readers are interested in — but if you look more broadly — you know, our understanding for example right now with work being done on neuroscience and understanding of the brain is absolutely extraordinary. You know we're starting to actually get a sense of what consciousness is; we're actually starting to get a sense of how

all of our behaviors are rooted in our neurophysiology and our brain chemistry.

We're even understanding things like how — how things that happen to you can actually influence your genome in a way that will change the way the brains that your children work. I mean it's just — and the understanding that we are coming to from all of that of not just the universe but of everything in it and especially of ourselves it's extraordinary.

Dave Eicher: And especially systems like living systems that are so complex with many, many thousands of compounds interacting within us all is remarkable to be able to decipher that and really incredible.

Jeff Hester: Yes.

Dave Eicher: I wonder if I might ask you about one thing about how science is perceived. It seems to be on a bit of a runaway train these days — and that is the reaction instantly — of course the Internet and cable news television — what remains of it — focused on anything beyond entertainment — you know, there's such a drive to have constant news continuously with social media, with the Net — but it seems like now there's an overreaction now, if you will, to every single paper, every study, everything that goes even institutionally through a press office you know is immediately rewriting much of what we know about this branch of astrophysics or whatever — or what have you.

Jeff Hester: Right.

Dave Eicher: There's a vast overreaction — and science actually is a slow accumulation of a weight of evidence together from many, many studies. And you know this is something that's really hard to deal with at the magazine and all the associated things that we do in that every story that you see on Facebook now claims to be a revolution, and it ain't.

Jeff Hester: And it ain't. It's really not. And then you know you follow those things up, and most of them you kind of never hear from again, you know — all of — cold fusion has played itself out big time.

Dave Eicher: Yeah.

Jeff Hester: One of the reasons for all of that is that science as an activity is kind of under attack these days. Once upon a time, you could be pretty sure that, "OK, I'm doing this science and there's something

there somewhere that people understand and support," and that's really no longer the case, ironically.

And I forget who it was — I don't remember if it was Don Savage or Ray Villard or Ed Weiler or somebody way back when, when we were doing Hubble press releases, made the comment to me that, "You know, Senators don't read *The Astrophysical Journal*, but they do read *The New York Times*." And I think that as you look at universities and organizations that they are increasingly relying on money that they can attract from donors, increasingly relying on somehow getting an edge out in front of the competition in a world where there are lots of players that ultimately there aren't going to be that many winners. And public relations is the stage upon which all that plays out.

And I think that public understanding of science is badly damaged by that.

Dave Eicher: And the pure quest for truth often gets lost in the politics.

Jeff Hester: Careful about talking about truth. You know, you say truth and you think about that big capital T out on the end of it and — you know, I'm not so worried about truth: I'm much more interested in knowledge.

Dave Eicher: Yeah, yeah, yeah. Yep. So what does that forecast for the near-term future for science — is this related to why you have gone and done what you're doing right now at this point in your life?

Jeff Hester: You know, it is. You know, having accomplished the things that I've accomplished as an astronomer, it was time for me to move on and do something else, you know, and I was not going to go back and — I have never been one to just kind of sit back and rest on my laurels, so it was time to go find some other interesting things to do.

What I am doing these days is actually taking that perspective and talking to individuals and organizations who are facing the reality of our times.

And the reality of our times is that the only thing you can really count on is change. And that's something that is new for humans. You know over the course of most of human history the challenges that you faced were pretty much the same as the challenges faced by your great-great-great-great grandparents. And it was really dangerous to question the notions of the group that you were in or

to break from tradition — because the very fact that you were there meant that those ideas couldn't be all that bad.

And so we have it built into us — you know, it's wired into our brains to want to hold on to group think, to tradition, to those kinds of things.

The reality on the ground today though is that we see more change in a matter of weeks than our ancestors saw in lifetimes. And if you want to succeed in today's world you have to figure out a way to stay on top of that.

And the model for how you stay on top of that quite frankly is science. You know science works by putting out lots of feelers and when something doesn't turn out to be the way that you thought it was, well gee, that tells you that that is a place where there are things to learn, where there's new opportunity.

Dave Eicher: So failure, if you will, Jeff, in science is as important in many respects as "success."

Jeff Hester: Oh man, it is. That when you go out and you're testing an idea, and the idea survives the test, OK, that's great: you have now helped solidify that part of knowledge.

But when you do something — like say I want to measure the rate at which the expansion of the universe is slowing down and you discover instead that the expansion of the universe is speeding up; you just blew a hole wide open, and it's a hole where there is all manner of new opportunities for new understanding, new insights.

And it's the same — you know, the universe will tell you when the tidal wave is coming, and the universe will tell you where to look for the next big idea, and all you have to do is know how to listen. And the way that you listen is you look at the ideas that are most precious to you, that — the ideas that people rely on the most firmly — and you do everything that you can do to find their flaws.

And if you find a flaw in something that you were really relying on — that you really thought was the case — then first of all you just avoided a catastrophe down the line somewhere — you know, most of the time we discover those when we go to rely on something and it didn't work out and all of the sudden we find ourselves scrambling to try to catch up.

But the other thing that you do is you identify opportunities for — well, you identify opportunities. If you're the first one out there to say, "Here's something that nobody else knows," or "Here's something that everybody else thought was the case but I know that it's not," you know that's an opportunity that you can drive a truck through.

And so what I'm doing these days is taking that experience with what is science experience working on projects like Hubble, you know, kind of having spent my career with one foot on the frontier of knowledge and the other in some of the hard practicalities of making complex projects work, and saying, "You know, this stuff has application outside of the roles of an astronomy classroom, and maybe I need to speak to a broader audience for a while."

Dave Eicher: And I'm sure they're appreciating those insights. One of the things that you said when we talked the other day that I thought was just an amazing line was given — what you just said relates to this — "Failure most often is the result of the world not being exactly what you think it is."

Jeff Hester: Yeah, that is absolutely the case. I mean we can — OK, I'm an astrophysicist so I will only very, very quietly admit that I actually go off and read things like business journals and such — and you know my colleagues who just heard me say this are going, "Oh god, he's lost it."

But there are all manners — all manners of work out there — like I was reading a study the other day that was not a study of businesses that have succeeded, but a study of businesses that failed, and what they realized was that about 80 percent of business failure comes ultimately from — the business school speak for it is *mismanagement of strategic risk*. But fundamentally what that means is that the world turned out to be other than what these people thought it was.

You know, they didn't recognize that the light at the end of the tunnel was in fact the headlight of the oncoming train.

Dave Eicher: Right.

Jeff Hester: And as a scientist, as an astrophysicist, as somebody who has lived on that edge of constantly challenging what you think that you know and making hay when you find out that there's something that didn't turn out like you expected it to — yeah, I feel like

maybe that you have something to say to a much broader community of people.

Dave Eicher: That's absolutely true. How do we get more people who are philosophic — I'm not talking politics here — philosophically conservative, who have had that hardwired, as you mentioned, in their brains for survival, for group dynamics over the past at least couple of hundred-thousand years — how do we get more people who were in this comfortable, predictable place to think scientifically?

Jeff Hester: There are kind of two answers to that question I think. One is just noting the fact that ultimately what humans are more than anything else is malleable. You know we got to the top of the heap by being able to adapt and by being able to handle the circumstances and by being able to move into new niches. I mean there's a reason why we are who we are. And we still have that capability.

I think though — the second thing is that you have to somehow convince people that they need to do that, and unfortunately quite often the only way to really convince them that they need to do that is to wait until things go very bad and they finally realize that, "Well, that's not working out for me. Maybe we need to try something else."

And that's kind of how — I mean you can sort of look at history and make the argument that that's kind of how things work: that people tend to be kind of complacent until it hits the fan in one way or another and then people scramble and figure out what needs to change.

Dave Eicher: And they really, really make changes when they're essentially forced into it.

Jeff Hester: And a remarkably small number of people can be responsible for those changes.

You know there's a movie out right now *The Imitation Game* about the life of Alan Turing. And you know the thought that here is one guy that most people have never even heard of quite frankly — but if you look he's the one individual who is most responsible — more responsible than anybody else for winning World War II — or at least World War II in the European theater.

He's the guy that is responsible for the invention of digital computers. You know, he is the guy that is responsible for our basic ideas about what artificial intelligence would be like.

You know, one person can make an extraordinary amount of difference in this world. And I know in working with students I always kind of kept that in mind: that you never knew which of your students — you know, that you manage to light a fire under, that you manage to kindle some curiosity and some passion under; that might go on to actually change the world in interesting ways.

Dave Eicher: And some of them certainly will. And it's an amazing thing given that we've come on this planet such a long way. And you mentioned earlier we understand the chemistry of the universe and that the chemistry of the cosmos and physics is the same everywhere we look and we're looking in real-time throughout the universe.

It's an amazing thing that we're just starting to come to grips with how life got a foothold on this planet and whether it was RNA — an RNA-dominated world — or lipids that got going that enabled things to go, or DNA first — but we're really getting a pretty good understanding now chemically of how the constituents of life from the universe led to eventually us — are we not as well?

Jeff Hester: You know, it's interesting because we are. A huge amount of progress has been made on understanding the specifics of those things.

But in a certain sense you don't even have to get the specifics right, because the real breakthrough in that is just understanding the inexorable algorithm of evolution.

And it's kind of funny because while a lot of people have argued in political and philosophical realms about evolution and such as that — engineers have gone off and just taken it and done stuff with it.

You know, for example, there's a really neat example that I use when I talk about this stuff, and it's a truss. Now a truss is just a thing that supports weight, it — everybody probably has in mind what it looks like; a couple of parallel rails with cross members — hey that's great.

What this team here in England somewhere — anyway, what they did was they said, "OK, we're going to take this thing, and we can write a computer program that will let us calculate the resonances

in this thing, calculate how badly it vibrates — because vibration in a truss is a bad thing."

And so what they did is they randomly varied the lengths of all of these cross members, and they evaluated each one of those. And the ones that were better they kind of kept and the ones that weren't so hot they threw away and then they took the ones that were better and they kind of jumbled their properties a little bit and varied them randomly again, you know, and then looked at those to see which ones were better. And they kind of ran through a bunch of generations of doing that.

And what they wound up with at the end was a think that looked like what you would get if you handed a box of Tinker Toys to a 3-year-old. But in terms of performance, the darn thing was four orders of magnitude — a factor of 10,000 — better than the original in the design properties, than it's — it's resonance properties.

And the genetic algorithms of that sort are now used to — they're used to design turbines in airplanes, they're used to design communications networks, they're used to design investment strategies, they're used to design computers, they're used to design the software that runs computers.

In fact we're in sort of an interesting time where you're using evolutionary algorithms to design the software that will design the next computers that will be used doing the next round of software that will be used to design the next computer.

And you find yourself with technology that is remarkably good at what it does. It's just that we don't know how it works or even exactly what it is that it's built to do anymore.

Anyway, that algorithm — that genetic algorithm — it's a matter of logical necessity: that if you have a set of individuals, if the properties of those individuals are different in some way, and if those properties determine the likelihood that the individuals will survive to pass it onto the next generation, then as a matter of logical necessity that population will evolve.

And again we're just hundreds and hundreds and hundreds of applications of this in an engineering sense these days. And then you step back for a second and you look at life and you say, "Wait a minute. Life satisfies those requirements." You know it's not a matter of we have to go back and reconstruct the fossil records to

see evolution. We're at the point where we can say that as a matter of logical necessity life must evolve.

And if you then go back and say, "OK, let's imagine that we just have a single molecule that has the property that it reproduces itself when it interacts chemically with its surrounding. And so what does it do?" Well, it reproduces itself so now you've got two of them. What do they do? Well they reproduce themselves and now you've got four of them.

OK. I turns out that no chemical process is 100 percent accurate, which means that things are going to go wrong in that, you know? And so let's just imagine that maybe one out of every ten billion times — one out of every 100,000 times the copying isn't perfect. And maybe one out of every 10 billion times when the copying isn't perfect it actually produces something that's a little bit better at reproducing itself.

Now those are extraordinarily long odds. And yet if you do that, you find out that over about the first 30 generations you've had something around 100,000 random changes that actually make the system better, and you say, "OK. Now what if you've actually got something like 4 billion years to let that process run?"

Dave Eicher: It's a long time to let it run.

Jeff Hester: It's a long time. And so — you know we understand a lot about the details of how life arose, and I think it's remarkable the details that we can reconstruct because that's hard to do — but in terms of understanding why it is that systems with the properties of life will just happen: that's an extraordinarily deep realization, an extraordinarily deep understanding.

And when you then look out at the universe and say, "OK, as we talked about earlier we know that other stars formed just like our Sun did. We know that planets form around them just like the Earth did, and we know they've got the same chemical elements, and yeah, we know all of those things." You look out there and say, "Man, that's an awful lot of opportunity for this juggernaut of an algorithm of evolution — this logically necessary process — to cause life to arise."

So it's — yeah, do the UFOs come and visit us? No, UFOs don't come and visit us. Is there other life out there? Yeah, there's other life out there and probably a lot of it.

Dave Eicher: Because we've got — set inflation aside — which I think we all agree we believe in — but that aside we've got something like, let's say 200 to 400 billion stars in the galaxy depending on how you average it at 125 billion galaxy — we've got maybe, you know, 50,000 billion-billion star systems at a minimum.

Jeff Hester: Yeah.

Dave Eicher: That's a lot of places to get some chemistry going.

Jeff Hester: That's an awful lot of places to get some chemistry going, especially when you know that it's chemistry that's not hard to get going and that once you get it going interesting things will happen.

You know, I still — you have to say, "What would be a really big thing to have happen?" I would love for them to find something on Mars or under the oceans of Europa, and when they find it I would love for its biochemistry to be completely different than ours.

And in fact there's every reason to imagine it would be. You know, it becomes a long discussion — probably too long for this interview — but if you really think about it, it is highly unlikely that any two planets in the entire universe have the same biochemistry.

Dave Eicher: Even all the potential biochemical paths.

Jeff Hester: Given all of the potential biochemical paths — there's some really fascinating laboratory work that's been done recently that shows that you can take things that have before occurred in nature and put them into biological systems and have them be active. And if you think about that, you say, "Oh, so you mean the particular proteins that we run on aren't the only proteins on which you can build life?" And the answer is, "Yeah." That the number of sets of proteins upon which you could potentially build life is a number that is so vast that it's — the likelihood that any two planets in our observable universe have exactly the same biochemistry is vanishingly small.

But you know if we found life on Mars, if we found life on Europa — even at the microbial level — anything — and it had a different biochemistry to our own then that would say you have twice within the same solar system where life arose independently. And that point the game's up. At that point you say, "OK, we now know that we're living in a universe that's just completely overrun with life."

Dave Eicher: Yes.

Jeff Hester: I don't know if you or I will live to see that. You know one of the unfortunate things, we get in a hurry and it would be great if we were going to be around personally to see everything that was going to happen, but that's not actually the way that things are.

Dave Eicher: It would certainly need to change the funding attitude of the U.S. Congress if you and I are going to see it.

Jeff Hester: Well, I — you know what? What is it, something like maybe seven percent of the world's population is in the United States — some number like that — there are an awful lot of other people out there that will step up and do it if we don't.

Dave Eicher: Yes.

Jeff Hester: I think that would be a sadness. I think that — irony is not the right word. It's — what made the United States what we are was our science and our technology and our willingness and ability to dream of things other than just bigger and bigger piles of money.

Dave Eicher: Right.

Jeff Hester: And — again back to Alan Turing that we talked about before — you know, or you look at where the transistor came from — or all of these things just revolutionized the world.

Dave Eicher: Yeah.

Jeff Hester: If you had insisted on "Let's only do things that are practical, let's only do things that are going to show up on this quarter's profit statement, or let's only do things that are going to help me get re-elected next time around," none of that would have happened.

Dave Eicher: Yeah, it would be a very different world.

Jeff Hester: It would be a very different world. And I am afraid — you know, the changes that are going on in the universities, which are becoming more and more corporate, more and more businesslike, less and less environments that are friendly to just curiosity-driven research, less and less environments where established not only scientist but people just across the spectrum of human endeavor work with the next generation to push back the frontiers.

As we move away from that towards a more and more corporate model of the university, I am afraid that what we're doing is we're killing the goose that laid the golden egg. We are undercutting the things that made our society as great as it is, and I think that's a sadness — but again, the reason that I think that that's a sadness is because this is where I happen to live and it means I see more of this stuff.

As far as humanity itself goes, I'd really love to be around in 200 or 300 years to see where we are.

Dave Eicher: That would really be something amazing. And I hate to say this — some additional sadness too — we're almost running out of time here Jeff, but I wonder — given what we've just said, what do you tell amateur astronomers — I mean aside from the practical troubles we face here on our planet this is a very exciting time, as we've talked about: we have more than ever to think about as we look out into the universe.

What would you say to amateur — to astronomy enthusiasts — about what's coming up in the next generation that we can look forward to in terms of exciting results?

Jeff Hester: Oh man. You know it's funny, I started out as an amateur astronomer — every time over the years when I've spoke to a group of amateur astronomers I've felt a little sheepish because I felt like they were looking — that I was up there actually getting paid for doing something that they were doing for just the love in their hearts.

Dave Eicher: Yeah.

Jeff Hester: Yeah, we've talked about a bunch of things but when it comes right back down to it take heart; revel in the discoveries and the remarkable understanding that you're having, because ultimately it's people who do that who carry the flame forward. You know, to people who embrace this, go out and talk to classrooms full of school kids, take your telescopes out there and show them Saturn so that some kid like me comes along and looks through a telescope and it changes his life.

Talk it up to your friends. Let your passion show.

Dave Eicher: And as you said, that can make a huge difference.

Jeff Hester: That can make a huge difference. And you know after all we can sit around and bemoan things that we're worried about all day long: it is a whole lot more fun and ultimately a whole lot more productive to spend all of that energy working on things that are remarkable and mind-blowing and positive.

And I can't tell you exactly what the future will bring, but I will tell you that there are people around right now, and including some young people who are listening to us chat right now, who are going to change the world. And we can be a part of that, and your listeners can be a part of it.

Dave Eicher: Well that's a very, very exciting way to conclude, Jeff. I thank you so much again for being our guest for this first-ever Superstars of Astronomy podcast today. Thank you so much. And the readers will see more from you coming up in the magazine that they don't know about yet, so stay tuned: You'll see more from Jeff Hester.

Thanks so much and good luck with everything that you're working on, Jeff.

Jeff Hester: All right, Dave. I had great fun with the interview and it was a pleasure to be here.

Dave Eicher: Thanks so much, we'll talk to you very soon, Jeff.

Jeff Hester: Take care.

Dave Eicher: Take care.