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'If our questions were valid, then pick up and try again'

David Leckrone is deputy associate director of sciences for the Space Telescope at NASA Goddard Space Flight Center in Greenbelt, Maryland. He was interviewed by David Cherry, associate editor of 21st Century Science & Technology, *on June 29 and July 2.*

Q: There are two questions concerning the Space Telescope mirrors: What is the error that was made, and why wasn't the error detected? Were the mirrors only tested against specifications, or were they actually employed to focus images, on the ground?

Leckrone: Let me back up a minute. I am really concerned about our assuming that we know what actually is the matter and what the cause of it was, until people have had a chance to meticulously go through all of the information. And that is going to take a little while to accomplish. So anything beyond that really is speculation.

In answer to your specific question, that part of the program was managed from the Marshall Space Flight Center [in Huntsville, Alabama], and they have the detailed knowledge of what went on. As I understand it, the two mirrors were never tested together as a single configuration. Rather, for that kind of test, was substituted a very exhaustive certification process of the mechanical and optical and computer system that was used to grind the mirrors.

So a design was created that allowed a test of the mirror against specifications through something called a null lens, and the purpose of the null lens was to give you a particular type of characteristic of the wave front of light bouncing off the mirror when the mirror had the correct shape. In other words, you would grind and polish the mirror, and then you shine a laser on it—it's the primary mirror I am talking about now—and the light comes out of the laser and is focused, and passes through this null lens, and if the wavefront passing through that lens has a particular simple character, spherical character, then it is presumed that the figure on the primary mirror is correct. That is the way the null lens is designed. That was all very meticulously designed and developed, and checked, and double-checked, and certified.

There is a mechanical-optical system called the metrology system that has the null lens in it, and it is part of the grinding and wavefront-error measurement system. So the test of truth in the grinding of the mirror wasn't so much direct measurement of the mirror system itself, but was rather a test of the character of the wavefront coming off of the mirror, as seen by this null lens.

Q: Is that test, in concept, a rigorous test?

Leckrone: Yes, it is a rigorous test. In concept, if it is done right, that should give you very, very high accuracy.

The theory of Ritchey-Chretien telescopes is very well understood, so the nature of the figure that you have to have on each of these two mirrors is very precisely known. In fact, when you specify the conic constants that define those mirrors, they are specified to something like seven decimal places, and the design and calculations and testing, and everything, takes you all the way out to the seventh decimal place. The kind of error we are talking about here would be an effect in the second or third decimal place.

Q: Which is therefore huge, even though it is only half of a wavelength.

Leckrone: It is enormous. It is immense. It is so big that we can't believe it. Therefore, there are a lot of us who think that there is a real mystery here.

Q: Someone I spoke to said, "Wouldn't it have to have been sabotage?" I said I didn't think so, but one must certainly look at all the possibilities.

Leckrone: That's right. If it were something subtle, then you know, we could all accept it as being a kind of unfortunate result of trying to push the state of the optical art. But there is nothing subtle about the second or third decimal place. If it is an error in manufacture—and again I want to be really careful not to prejudge that—it is a *monumental* error.

Q: So NASA scientists and engineers are addressing the question of what other phenomena could produce such a result, if the mirror were figured correctly?

Leckrone: Yes. We have gone through, and are still going through—"we" meaning the project engineers, the people I

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talk to are doing it—agonizingly going through everything that might be going wrong even on the spacecraft, for example. Thermal control, the differences in stresses on the mirror after it was released from the 1-*g* environment, that kind of thing. And frankly everyone has just racked their brains and can't think of any plausible explanation. All of those things were thought about well in advance and all very carefully planned for.

We had the thermal vacuum test at Lockheed, where the thermal control system was very rigorously tested, for example. It turned out that the mirror was running too cool—the measured temperatures on the mirror were cooler than the model-predicted temperatures. They traced that down to a misunderstanding about the exact value of the emissivity of the front surface of the mirror. So when they corrected that value in their calculations, the model gave very close agreement with the actual measurements. So it is assumed that the thermal control system is well understood at this point, and is accurately described by our models as tested.

Any explanation that would involve the thermal control of the mirrors, would have to somehow be something that has slipped in outside the boundaries of the model that we are working with. And that's just very hard to conceive of.

Q: People have spoken of putting corrective mirrors in the light paths of the instruments, but they can only compensate for the aberration within the tolerances that you can control in figuring a much smaller surface area than either of the two mirrors has.

Leckrone: That's true, but the tolerances don't seem to be *that* severe. We have already done some numerical simulations for the second-generation Wide Field/Planetary Camera, and it looks like it is a very simple figure to grind, because the aberration itself is so simple. It is elementary spherical aberration that is easily described by a single coefficient in an equation and is very symmetrical, very well behaved. It's a textbook case. So there should really be no technical challenge in grinding a similar, very simple, symmetrical corrective surface on a small mirror, I think about the size of a quarter.

Q: Can those corrective surfaces be applied for all the instruments?

Leckrone: The situation is a little bit different in each of the three advanced instruments. WF/PC II, just like WF/PC I, has eight little telescopes inside it, each of which focuses the beam emerging from the Optical Telescope Assembly onto a charge-coupled device, and these are called repeaters. The compensating figure would be introduced into the secondary mirrors in those eight little telescopes. That's possible, because those secondary mirrors are very close to what's called the pupil plane of the Optical Telescope Assembly, just where you would have to put an optical surface to collect all of the aberrated wavefront and introduce the compensation.

Similarly in the NICMOS—our Near Infrared Camera and Multi-Object Spectrometer—there is a mirror near the pupil plane of the telescope within the optical train of the instrument design. It is ideally situated for an optical corrective figure. It hasn't gone to hardware yet; it's still in the paper design phase.

With STIS—the third of the second-generation instruments, Space Telescope Imaging Spectrograph—the situation is a little more complicated, because you have to correct the aberration before the light enters the entrance aperture of the spectrograph. Right now, the entrance aperture is planned to be right up at the front of the instrument. So there is no physical space for the correction optic.

The plan is to lift up the whole present design of the STIS within the box that houses it, and there is some room to do that. In the space created by doing that, two additional mirrors will be introduced into the light path, and one them will have the corrections built into it.

The STIS and NICMOS are also slightly more complicated because they are off-axis—off the optical axis of the telescope. There is already a little bit of astigmatism for the off-axis instruments that was going to be there anyway. So you have to simultaneously compensate for two different aberrations. There are experienced optical designers already thinking about this, and who already have the design solutions written down.

Q: Do you have data from these past two weeks that give you confidence that, whatever turns out to be the *cause* of this spherical aberration, that it really is spherical aberration, and that these additional features will correct it?

Leckrone: All I can tell you is that, of course, we are not going to make any changes in anything, until we are 100% certain that this is the problem. Right now, I can tell you that I have looked at the data, and I have seen the smoking gun, and if it is not spherical aberration, it is the twin brother. It's a classic, textbook case. However, I have heard at least one optics person say, that occasionally you can get other types of problems in optical systems that might mimic some aspects of spherical aberration. So we are going to look into that. I think that's grasping at a straw somewhat.

In any event, whatever we have is an aberration that is very simple, very symmetrical, and almost certainly could be corrected, whether you label it spherical aberration or something else.

Q: How are ultraviolet and infrared observations going to be affected?

Leckrone: They are very much less affected than imaging. Even in the imaging observations, there are still some wonderful things we are going to be able to do, even with the image we now have. The image as it now is still has a very sharp central spike in it that is very much like what we wanted. The image, in its center, looks just like we wanted; it's just that that central spike doesn't have all of the light in it that it was supposed to have. Most of that light has now been washed out around the central spike.

Q: So observations must be adjusted to allow for longer exposures?
Leckrone: That's exactly right. On the spectrographs and the photometer and so forth—particularly on the spectrographs—we will be able to do the very same things we could before, but it's going to take longer exposure times, because we are going to get less of the light into the very small entrance apertures of those instruments. But other than that, the basic science of those instruments is still feasible. It will take a little bit longer to do, and maybe we won't be able to pack quite so much of the science into a particular amount of time because of this loss of efficiency. But the basic science is still intact, and will still be done.

Q: Is it feasible to get the second-generation instruments up there with these correctives in three, six, or seven years, or might it take longer?
Leckrone: These things were already in our program. We have a program of in-orbit servicing already laid out and under way, as a routine part of maintenance of the observatory, that will give it its full 15-year life. When people throw around this figure of $200 million a year operating cost, that's a misconception, because the $200 million includes the cost of this in-orbit maintenance program, as well as the cost of actually operating the ground system, and so on. So in the flow of that program we had already scheduled Shuttle flights for 1993, 1996, and 1997. We are already in the manifest. We already have the WF/PC II being built with a launch-readiness date of 1993. We would not have flown the WF/PC II if everything was going very well and there was no reason to go up there. If it wasn't "broke," there would be no reason to fix it. But we were in a position to be ready to make a routine servicing flight carrying WF/PC II and other pieces of equipment in 1993. Instead of that being an option, we now know that we need to do it.

The NICMOS was scheduled for launch-readiness in 1996, and the STIS for 1997. We will look at trying to accelerate there a little. But we are not going to be hasty—we still want to do it right.

The interview continued on July 2:

Q: What was done to assure that the primary mirror wouldn't wind up with a different figure when it was moved from 1-*g* to space?
Leckrone: The gravitational deformation of the mirror was included in its design. That was just about the first thing I asked when I found out about this—was the gravity release somehow miscalculated or something. Apparently that was all very thoroughly worked out. Again, we have it on the list of things to be looking into.

Q: Is anyone thinking that eight years of sitting in Earth's gravity might have caused this problem in the primary? *The Space Telescope,* by George Field of Harvard and Donald Goldsmith flatly asserts, "The Space Telescope's mirror is strong enough to maintain its shape precisely while in free-fall in an orbit around the Earth, though it would not be strong enough for a telescope on the ground." [Contemporary Books, 1989, p. 18]
Leckrone: That's a good point. A support structure called a "bed of nails" was used to guard against sagging over the long waiting time.

Q: There is no particular news since we talked last?
Leckrone: No, not at all. All we can tell you is our best hypothesis as to what the cause of the problem might have been—namely a figuring error. That's not to say that there may not be more subtle effects [suggesting something else] when one collects more data and looks at it more closely. And we are doing that, with the wavefront sensors in the Fine Guidance System and with the Faint Object Camera. So we are going to get high-quality independent data from two other instruments on board the observatory besides the WF/PC, and find out whether or not they are in total agreement with the data obtained with the WF/PC.

We are definitely in an open-minded mode, leaving no stone unturned to verify with certainty what the cause of this phenomenon is.

Q: The response of some people in Congress and certainly the mass media seems to be based upon an eagerness to kill a lot of programs. This is just red meat for them. They seem to have no interest in the achievement of *any* long-term objectives.
Leckrone: Yes, undoubtedly there are people in Congress who are definitely not supporters or advocates of NASA programs, who will point to this as just reinforcing their own points of view. There are people who are definitely our friends in Congress, and even they, of course, have a right to be upset, as we are all very upset. But it would be an even worse catastrophe for people to just throw the program down the tubes.

The reason we do things like the Space Telescope in the first place, is that we dare to dream—I won't say *impossible* dreams—but we aim very high as a civilization. We ask very tough questions. And we actually dare to try to find answers. The real question is, whether this is a valid process in our culture. If the questions are still valid questions, and our motives for doing this sort of program are still valid motives, then what we ought to do is pick ourselves up off the ground and try again. If we are unwilling to pick ourselves up off the ground and try again, then one may question whether we are really such advanced creatures as we thought we were.