NASA

National Aeronautics and
Space Administration

Washington, D.C.
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Reply to Attn of: SZB

Mr. Juan J. Schulz Poquet
Defensa 1532
1706 HAEDO - Buenos Aires
ARGENTINA

Dear Mr. Poquet:

Thank you for your letter dated July 14, 1992, regarding the imaging problem associated with the Hubble Space Telescope (HST). We have also received the copy transmitted through the United States Embassy in Buenos Aires.

In your letter, you both describe an experiment designed to measure properties associated with the ether hypothesis for the propagation of light and propose that the existence of such an ether could explain the image distortion associated with the HST optical system. I appreciate your taking the time to share your thoughts with us.

Following its April 25, 1990, deployment, it was found that the images produced by HST were not what was expected. Rather than producing diffraction-limited stellar images, the telescope instead produced images characteristic of a very specific kind of optical aberration. It is important to note that the character of this aberration is not the same as that associated with simple defocus. The telescope was, in fact, refocussed many times, always producing a distorted image. The mirror distortion required to produce the observed image distortion is commonly encountered in large telescope optics and is known as spherical aberration. Simply put, it results from the curved-surface mirror being ground to slightly too flat a figure. In the case of HST, the excessive flatness, as measured at the extreme edge of the mirror, amounts to 0.02 of the width of a human hair.

Further evidence for the image distortion resulting from spherical aberration is the fact that the two imaging cameras on HST, the Wide Field/Planetary Camera (WF/PC) and the Faint Object Camera (FOC), depend on different internal optics, which would be differently affected if the primary mirror were incorrectly figured. In fact, the two telescopes show image distortions which differ in just the way that would be expected were spherical aberration present.

Finally, and perhaps most importantly, the metrology equipment used to fabricate the HST primary mirror, sometimes called the "fossil evidence," had been preserved at the vendor's facility and was available for examination. It was found that subtle errors in a key device, the "Null Corrector," would have produced a primary mirror error exactly like that observed on orbit.

The conclusion at which we, and independent panels of experts, have arrived is that the observed behavior of the HST mirror is fully explained by the hypothesis that spherical aberration is present and that the observed effect is exactly what one would expect based on the fossil evidence. There is no evidence of any other (unexplained) effect.

I found the description of your thoughts on relativity interesting. While I suspect that members of the physics community might find your efforts controversial, I congratulate you on your enthusiasm for science and scientific investigation. I would note that under our standard "no exchange of funds" rule, NASA does not support scientific research outside of this country.

I have enclosed several documents describing the current state of the telescope, recent results and plans for the future, and a succinct description of the optical problem. I wish to thank you again for your interest in NASA programs.

Sincerely,

L. A. Fisk

L. A. Fisk
Associate Administrator for
Space Science and Applications

3 Enclosures

THE FOLLOWING MATERIAL APPEARED IN THE NASA ASTROPHYSICS DIVISION NEWSLETTER IN EARLY 1992:

With over 100 observing programs now completed, the Hubble Space Telescope (HST) is providing many scientific surprises. Nevertheless, although the spacecraft is operating beautifully, NASA continues to place the highest priority on installing corrective optics to overcome the limitations resulting from a flaw in the fabrication of the primary mirror. Here, we answer some commonly asked questions about the HST optics.

Q: What's the problem?

A: Soon after first light, HST was found to suffer from spherical aberration. That is, starlight that hits the outer rim of the primary mirror comes to a focus behind light that passes closest to the center of the primary. The result is that no single focal plane position yields the sharp images for which the telescope optics were designed. The type of spherical aberration which has been discovered is called "overcorrected" — the primary mirror was polished too flat by about two microns.

Q: How do we know that it is spherical aberration resulting from a manufacturing error and not some other flaw?

A: The spherical aberration seen in the images is extremely uniform in all radial directions; this points to the primary mirror.

Q: How did NASA measure the exact figure of the HST mirror system while it was on-orbit ?

A: The three sources of information used to derive the precise shape of the mirror were: (1) images from the Wide Field and Planetary Camera (WF/PC); (2) images from the Faint Object Camera (FOC); and (3), investigation of the reflective null corrector used to test the primary mirror on the ground.

Q: How do we know that the aberration lies only on the primary mirror and not on the secondary mirror?

A: If there were a flaw on the secondary mirror, another aberration called *field-dependent coma* would appear in off-axis images. In addition, an identical secondary mirror had been made as a backup simultaneously with the flight mirror. The two mirrors were worked interchangeably, and the one that remains on the ground was measured and found to be near-perfect.

The final reason to believe that all of the aberration is on the primary mirror is the discovery by the investigative committee, led by Lou Allen, that a major mistake was made in the calibration of the prime tool for figuring the primary mirror. This tool was called a reflective null corrector (RNC), and required precise spacing of components to work properly. The Allen commission discovered that chipped paint, on a small cap placed on a metering rod, caused a spacing error of 1.3 mm that went undetected. The result was that, in order to make the mirror test perfectly with the flawed RNC, the mirror itself had to be polished to the wrong shape.

Q What did NASA do to measure and characterize the magnitude and sign of the spherical aberration on the HST optics ?

A: The final prescription was provided by analysis of images from both HST cameras and by precision metrology of the RNC. The work with the images combines mathematics and physical optics in a process called *phase retrieval* to derive the optical aberration coefficients. The precision measurements of the RNC at Danbury (Connecticut) led to an understanding of the cause of the aberration.

Q How was all of this data evaluated and converted to an optical prescription ?

A: The task of evaluating the measurements from the on-orbit images and the RNC was given to the HST Independent Optical Review Panel, chaired by Professor Duncan Moore, Director of the Institute of Optics at the University of Rochester. This was the first time that the prescription of an optical telescope launched and on orbit had been measured and defined while it was in orbit.

Q How do we know that the prescription is correct?

A: There is agreement between (1) the phase retrieval results from the two HST cameras and (2) there is agreement within the error bars with the RNC measurements at Danbury . In addition, (3) model studies of the performance of the three Fine Guidance Sensors (FGS) onboard HST indicate the same prescription.

Q How is NASA going to correct the spherical aberration on HST?

A: The simplest way to correct the aberration is to polish the opposite surface correction into an optical element at a pupil. The two approaches to this are the WF/PC II instrument, which has small relay telescopes which have a pupil image on their secondary mirrors, and the Corrective Optics Space Telescope Axial Replacement (COSTAR) which will deploy pairs of mirrors (one corrective) between the secondary mirror and the optical train of the Faint Object Camera, the Faint Object Spectrograph, and the Goddard High Resolution Spectrograph.

Q How do we know that the WF/PC II and COSTAR optics will correct the aberration?

A: (1) The manufacturer of the mirrors, Tinsley Laboratories, is performing three independent verification tests on the COSTAR and WF/ PC II mirrors: profilometry, a computer generated hologram interferometric test and, with a different interferometer, a refractive null lens test.

(2) The manufacturers of WF/PC II and COSTAR, JPL and Ball, respectively, are planning a series of alignment and wavefront error tests to catch errors in the correction by the mirrors at an early stage. Ball and JPL are each building aberrated beam simulators which will test their instruments against an optical input that closely simulates an HST aberrated star image.

(3) The Space Telescope Science Institute will independently provide staff experts and computer support to assist in the ground verification and alignment of both the WF/PC II and COSTAR instruments. Among the independent tests to be conducted is phase retrieval, on the corrected images, to enable the actuators on the instruments to be moved for final on-orbit alignment.

(4) The European Space Agency is providing a refurbished FOC Structural and Thermal Model (STM), using flight backup optics and modern CCD cameras, to aid in the verification and alignment of COSTAR. When the FOC/STM receives light produced by the Ball aberrated beam simulator, the image corrected by COSTAR should match the nominal corrected FOC image.

(5) The Independent Verification Team (IVT) from the Engineering Directorate's Space Technology Division at NASA Goddard Space Flight Center has been tasked to verify the HST optics recovery program. The IVT is building an Aberrated Beam Analyzer,

which will be taken to JPL and Ball, to verify the wavefronts generated by the aberrated beam simulators at each contractor. The test results on the aberration simulators at JPL and Ball should match each other, as well as themeasured value of the aberration on orbit. The IVT is also involved in verifying models by analysis and phase retrieval of images.

(6) The HST Flight Systems and Servicing Project at Goddard has the final responsibility for the verification of the overall HST corrective optics program. Dr. H. John Wood, HST Optics Lead Engineer, has already performed a quick but effective "sanity check" by using a simple measurement of the shape of the aberrated beam produced by the first wide field relay, and confirmed it again with a simple null lens built in-house at Goddard.