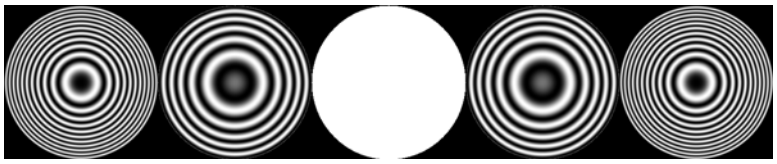
Section 4.7 – Interferograms

Defocus

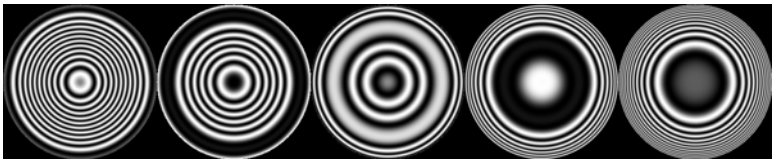


Defocus & Y-Tilt

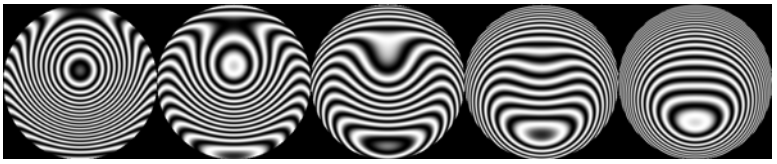
W_{020} -2 μm -1 μm 0μm 1 μm 2 μm

Section 4.7 – Interferograms

Spherical Aberration



Spherical Aberration & Y-Tilt

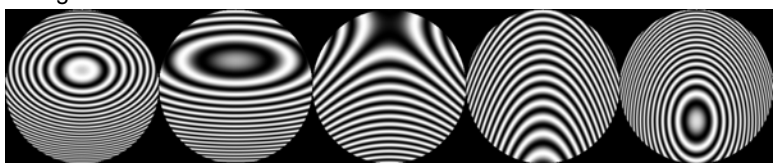


W_{020} -2 μm -1 μm 0μm 1 μm 2 μm

Section 4.7 – Interferograms

Astigmatism

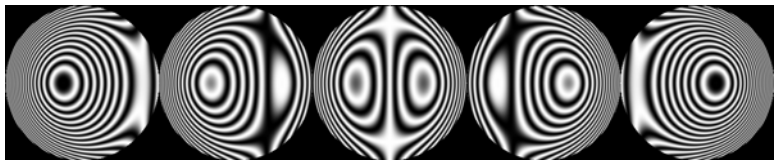
Astigmatism & Y-Tilt



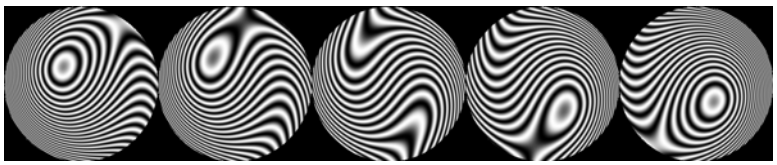
W_{020} -2 μm -1 μm 0μm 1 μm 2 μm

Section 4.7 – Interferograms

Coma

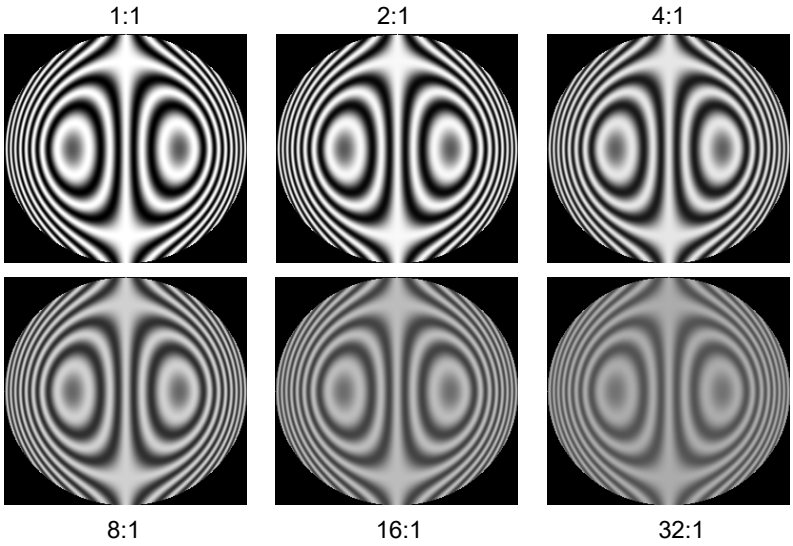


Coma & Y-Tilt

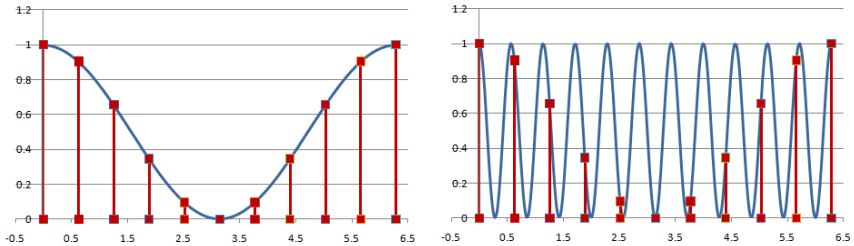


W_{020} -2 μm -1 μm 0μm 1 μm 2 μm

Relative Intensities

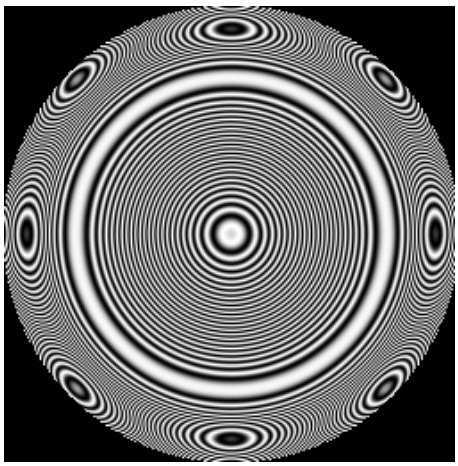


Aliasing

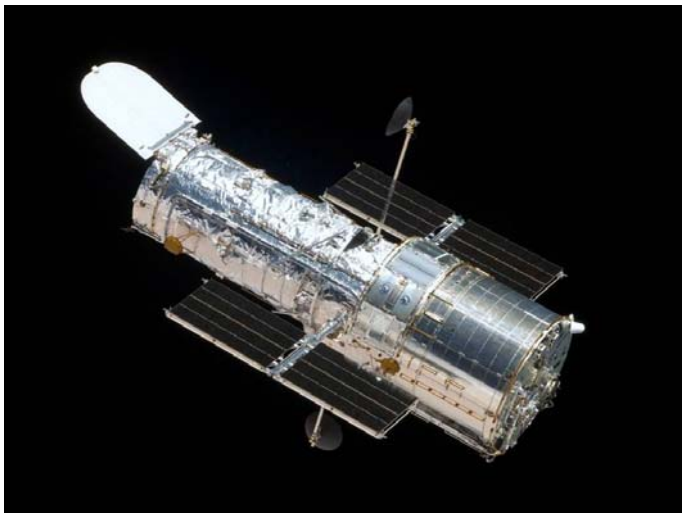


Sampling a low frequency pattern accurately approximates the curve, but when high frequency patterns are sampled, the pattern is reduced to a lower frequency shape.

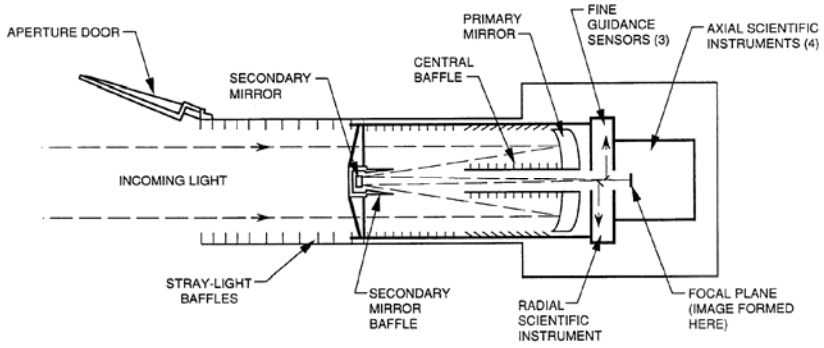
Aliasing



Hubble Telescope



Hubble Telescope



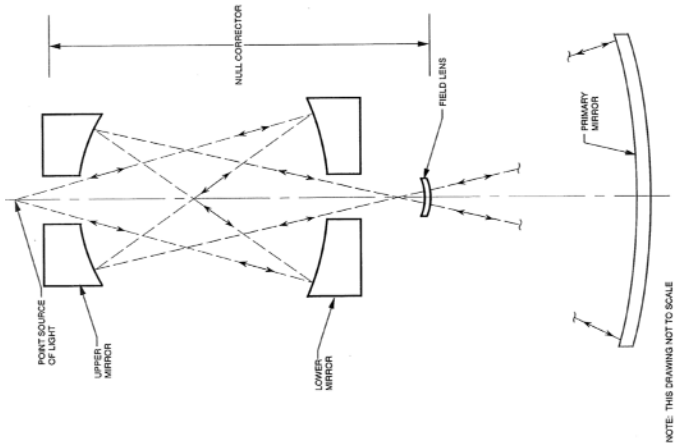
Ritchey-Chretien telescope with 2.4 m primary mirror.

Aberrations

Before Repairs

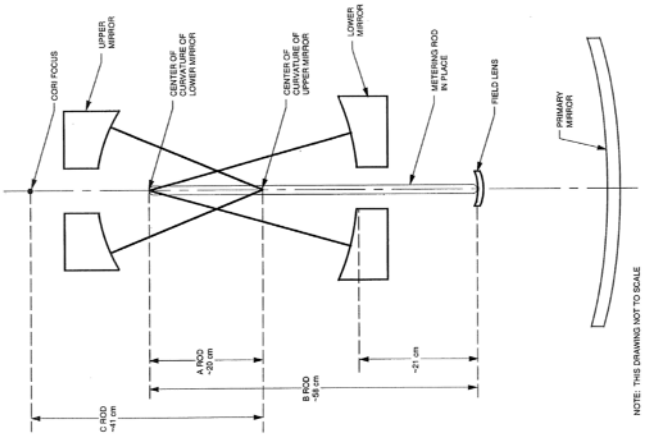
After Repairs

Reflective Null Corrector



Reflective null corrector converts incident spherical wave into a suitable shape to retro-reflect from the primary mirror

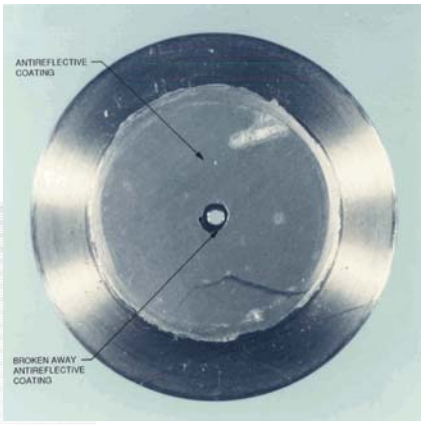
Reflective Null Alignment

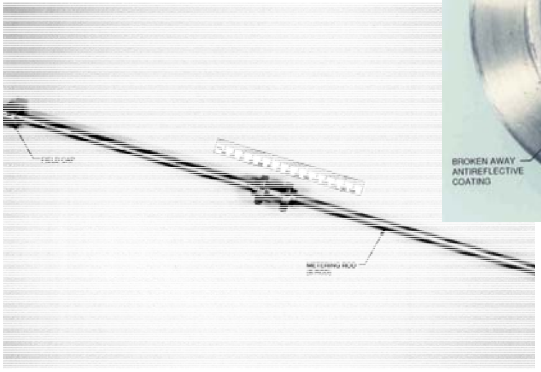


Metal rods with rounded ends were used to set the spacing between the mirrors and the field lens. An interferometer is used to precisely locate the end of the rod through retro-reflection.

Rod Caps

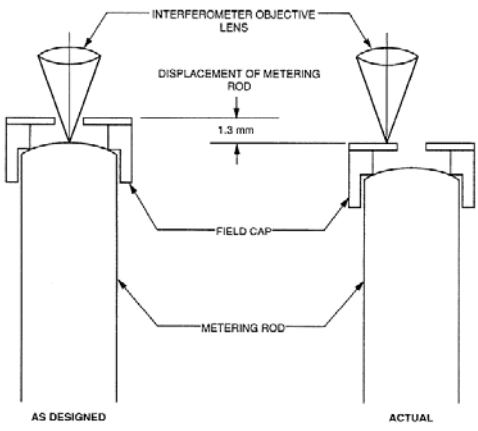
Caps were placed on the ends of the rods to help make sure the rod was centered. The rod was visible through a small hole in the cap. The end of the cap had an anti-reflective coating applied to it.





Some of the anti-reflective coating in the neighbor of the hole had broken away.

Misalignment of Field Lens



Unfortunately, when locating the end of the rod for position the field lens, the operator got a retro-reflection off the field cap instead of the rod. This ultimately led to a 1.3 mm displacement in the axial position of the field lens and an incorrect amount of spherical aberration in the reflective null corrector. This spherical aberration in turn was polished into the primary mirror.

Failure Report

THE HUBBLE SPACE TELESCOPE

OPTICAL SYSTEMS FAILURE REPORT

Dr. Lew Allen, Chairman
Director, Jet Propulsion Laboratory

Dr. Roger Angel
Professor of Astronomy, Steward Observatory
University of Arizona

Mr. John D. Mangus
Head, Optics Branch, Space Technology Division
NASA/Goddard Space Flight Center

Mr. George A. Rodney
Associate Administrator for Safety and Mission Quality
NASA Headquarters

Professor Robert R. Shannon
Director, Optical Sciences Center
University of Arizona

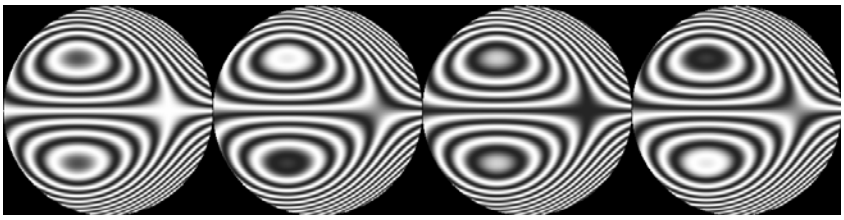
Mr. Charles P. Spoelhof
Vice President (Retired), Eastman Kodak Company

These errors were identified by a team of independent scientists. Ultimately, corrective optics were developed and deployed based on the failure report and the image quality of the repaired telescope has led to unprecedented images of the universe.

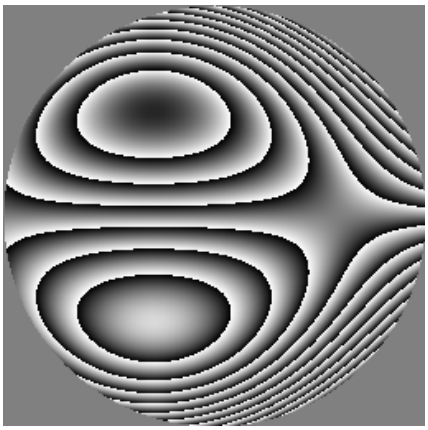
Four-Step Algorithm

Phase Shift

0 $\pi/2$ π $3\pi/2$



Wrapped Phase



$$\varphi(x,y) = \tan^{-1}\left[\frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}\right]$$