1997 HST Calibration Workshop
Space Telescope Science Institute, 1997
S. Casertano, et al., eds.

Simulations of the STIS CCD Clear Imaging Mode PSF

R.H. Cornett

Hughes STX, Code 681, NASA/GSFC, Greenbelt MD 20771

A. Grusczak

Hughes Danbury Optical Systems, Danbury, CT

C. Ftaclas

Michigan Technological Univ., Physics Dept.,1400 Townsend Dr., Houghton, MI 49931-1295

S.R. Heap and B.E. Woodgate

Laboratory for Astronomy and Solar Physics, Code 681, NASA/GSFC, Greenbelt MD 20771

Abstract.

Detailed understanding of the properties of the point-spread function (PSF) of STIS imaging modes is necessary to separate real effects of geometrically complex astronomical sources, such as protoplanetary disks surrounding bright stars, from instrumental effects, such as scattering and diffraction. In order to investigate STIS imaging properties we have numerically simulated broadband stellar PSFs generated by STIS in CCD clear imaging mode, including the effects of the Lyot stop and the coronagraphic wedges. The input spectrum is a stellar model atmosphere of the appropriate spectral type, convolved with the pre-flight STIS CCD response function. The PSF modeler generates broadband PSFs by co-adding weighted monochromatic PSFs across the waveband.

1. Introduction

Several key STIS observation programs depend critically on the details of the STIS PSF. The STIS clear imaging PSF is influenced by the HST input PSF, including its scattering, phase errors, and other effects, as well as novel STIS instrumental features such as the complement of coronagraphic bars and the Lyot stop. We have begun a program to numerically simulate the broadband stellar PSFs generated by STIS in CCD clear imaging mode (3.6), including the effects of the Lyot stop and the coronagraphic wedges.

The purpose of this paper is twofold: a) to describe the characteristics and operation of the STIS coronagraph bars and Lyot stops, which may not be well known or understood; and b) to describe a program of modeling STIS performance using these instrumental features, its results to date, and future plans.

2. The STIS Clear CCD Imaging Mode

The clear CCD imaging mode light path leaves the STIS corrector optics to pass through the coronagraphic aperture mask, located at the first STIS focal plane on the slit wheel.

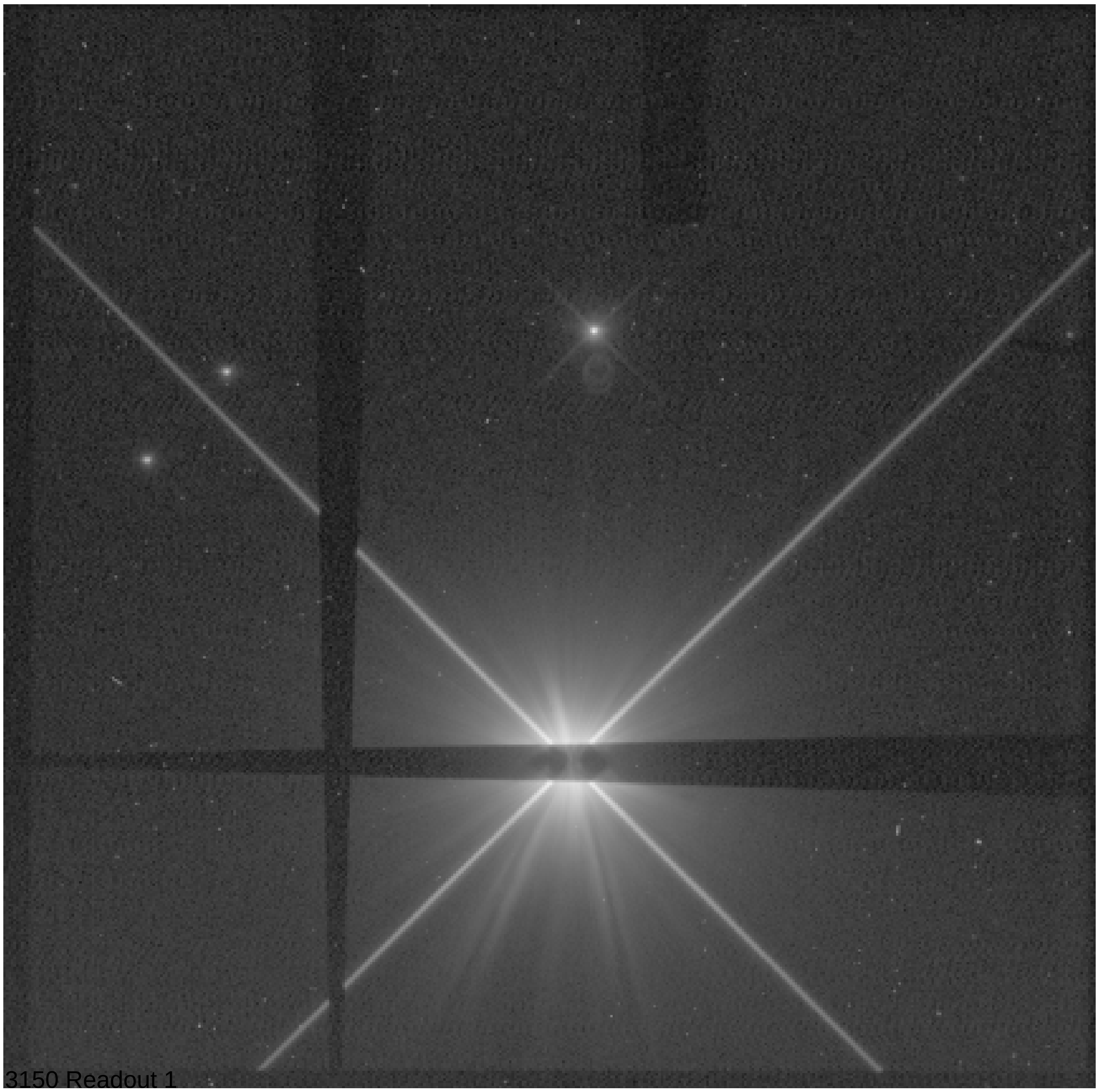

Figure 1. A clear-CCD-mode image of the HST standard star HD60753 positioned to intercept a coronagraph bar, from SMOV program 7088. The square field is 50 arcsec across; the large rectangular bar is 3 arcsec by 10 arcsec; the tapered bars are from 0.5 arcsec to 3 arcsec in width (1.8 arcsec at HD60753's location); and the crooked bar is 0.5 arcsec wide. The exposure duration is 1800 sec.

Subsequently, it encounters the fixed ellipsoidal collimator, a camera flat mirror located on the grating wheel at the second pupil plane, the Lyot stop aperture (which is fixed a few millimeters from the camera flat mirror), a folding flat, the ellipsoidal camera mirror, and the CCD detector. Figure 1 shows the CCD image plane with the coronagraphic aperture mask.

3. The STIS PSF Modeler Software (SPM)

The SPM software (Ftaclas *et al.* 1994) simulates PSFs for STIS in the clear CCD camera mode. As currently configured, it can produce broadband PSFs for any stellar input spectrum (represented by model atmospheres), and it can simulate PSFs with varying amounts of focus error due to changes in the Optical Telescope Assembly (OTA) secondary mirror.

SPM uses a diffractive propagator to simulate the propagation of light through the STIS camera. STIS has a focal plane mask which includes the coronagraphic occulting bars at the first focal plane, and a Lyot stop approximately at the second pupil plane. The model can represent a PSF placed at any location in the focal plane, and the Lyot stop may be adjusted in size or removed altogether. The basic logic of the SPM diffractive propagator module is as follows.

SPM first determines overall weights for each wavelength by multiplying the stellar spectrum by the CCD response function. Then, for each wavelength in the PSF being constructed:

- User-specified phase errors are applied to the OTA pupil
- Light is propagated to the first focal plane where the wavelength– appropriate focal plane mask (the coronagraphic wedge set) is applied
- Light is propagated to the second focal plane, where the PSF is computed
- The monochromatic PSF is normalized

Monochromatic PSFs are then co-added to form a broadband PSF, which is output as an image in FITS format.

A comparison of an SPM output PSF and an observed STIS PSF is shown in Figure 2.

4. Lyot Stops and Coronagraphic Images

Coronagraphs employ a baffle in a focal plane to block light from a central bright source (*e.g.* a star), to permit study of fainter nearby objects (*e.g.* a protoplanetary disk). "Error" light in the wings of the stellar PSF, caused by diffraction of central-source light from the edges of the telescope aperture or spider, or, in the case of HST, light with phase errors from the sagged edges of the primary mirror, may still dominate in that part of the image. A Lyot stop is a baffle in a pupil plane shaped to block light from the dominant error sources. In the case of STIS, the Lyot stop is not precisely at a pupil, so an approximate shape was chosen– a circular aperture– which eliminates most diffracted light from the aperture edge as well as light having phase errors caused by mirror sag. In the STIS instrument, the Lyot stop (a circular opening in a baffle mounted a few millimeters above the camera flat mirror) is always in place in clear CCD imaging mode. The model will permit "removing" the Lyot stop to test its effects, although we have not yet modeled the relevant situation in which phase errors, simulating primary mirror sag, are input at the OTA pupil.

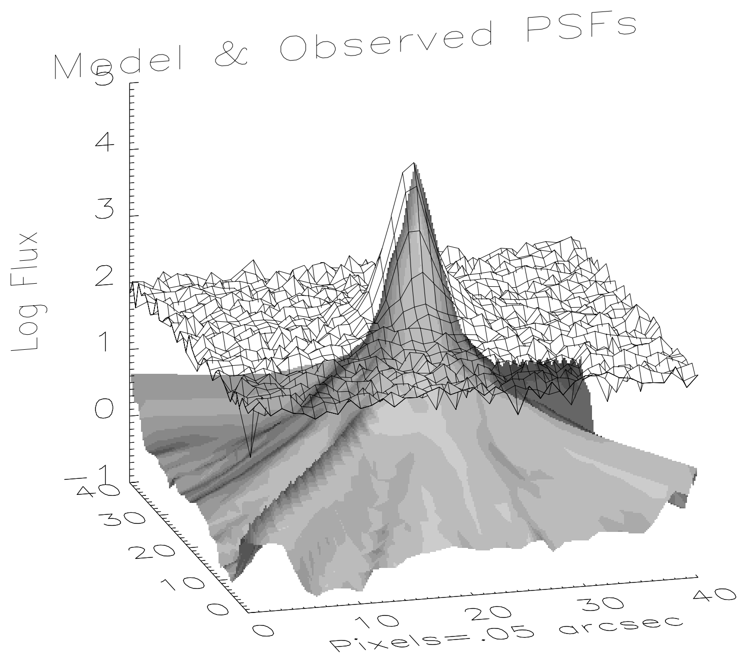

Figure 2. SPM model output (shaded surface) for a star represented by a Kurucz (1992) model atmosphere with T_{eff}=10,000 K located at the center of the STIS image plane, well away from coronagraph bars, superimposed on (wire-grid surface) a subarray of an observed image of the DA1 white dwarf GD153, from SMOV program 7070, for similar conditions. The PSFs have been normalized to the same peak height; the displayed image area is 2.0 arcsec square, the model's current capability. A "floor" of about .3% of the peak height has been added to the observed image to remove negative values. The measured FWHM of the model PSF is 1.26 pixels (.063 arcsec) in both x and y, while for the observed PSF the values are 2.01 pixels (.100 arcsec) and 1.65 pixels(.082 arcsec) in x and y respectively. The difference is due to misalignments, image motion, and scattering from unmodeled sources such as the detector (which depends strongly on wavelength) and background.

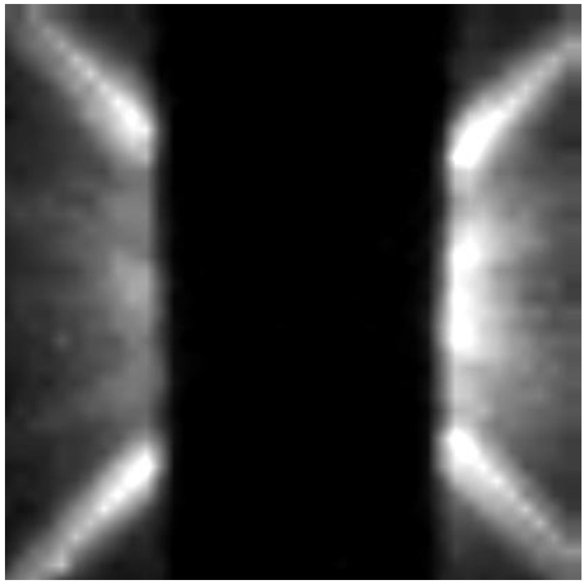

Figure 3. **The Model and Real Coronagraphic Images:** A comparison of a coronagraphic image (above) of the DA1 white dwarf GD153 from SMOV program 7070 with results of a model calculation (Figure 4, below), over the model's current field size of 2 arcsec square. In the model calculation, the star's position has been moved off the center of the bar to give the same net flux asymmetry as the observed image. The two images are normalized to the same total flux and displayed with the same grayscale. The model evidently reproduces major features well, although the effects of scattering and noise sources which are not simulated by the model are manifested in higher peaks and lower background. The model confirms the instrumental origin of several faint radial "rays" which have the potential to be confused with observed objects (*cf* Figure 1). The "beaded" appearance is due to numerical effects of image resampling.

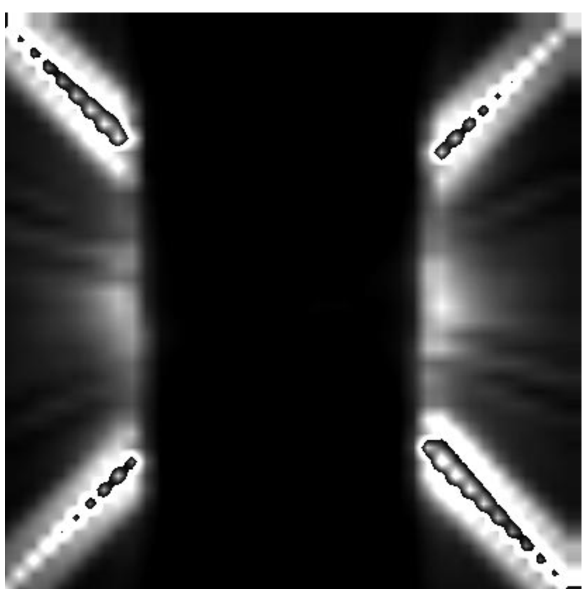

Figure 4.

5. Future Work

As described above, the STIS Lyot stop is designed to remove error-dominated light from the sagged outer part of the OTA mirror, as well as light diffracted from the OTA outer boundary. The model permits introducing appropriate phase errors on an OTA phase map; we have acquired the OTA phase map as defined by the WFPC2 team, and will introduce that map as input. These data will permit much more realistic modeling of the Lyot stop performance.

The model is currently limited by the relatively small size (2 arcsec square) of the modeled PSF image, initially held to this size because of computational restrictions. To better simulate observations we will increase the output PSF size to better define "rays" such as those seen in Figure 1, and which must be distinguished from real image features for many scientific programs.

References

Ftaclas, C., Nonnenmacher, A. L., Grusczak, A., Terrile, R. J., & Pravdo, S.H. 1994, Proc. SPIE Vol. 2198, p. 1324-1335, *Instrumentation in Astronomy VIII*, David L. Crawford; Eric R. Craine; Eds.

Kimble, et al. 1997, ApJ(submitted).

Kurucz, R.L. 1992, in *The Stellar Populations of Galaxies*, ed. B. Barbuy & A. Renzini (Dordrecht: Kluwer), 225.