



**Technical memo number 10 -- January 2005**

**REMOVAL OF THE H $\alpha$  GHOST IMAGE FROM STIS CCD DATA**

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(If you use information or advice from this memo, please acknowledge it and the net site <http://etacar.umn.edu> in any resulting publications; thanks.)

## **1. Introduction**

The STIS Instrument Development Team established that the optics of the STIS generate ghost images on the CCD (Gull et al., 2002; Hill, 2000). Hill developed a comprehensive empirical model of the behavior although the detailed origins of the ghosts are as yet unidentified.

In our Treasury Project data, a large diffuse ghost is noticeable only near the very bright H $\alpha$  emission, appearing at smaller row numbers and larger column numbers (larger apparent wavelength) than the real feature (Figure 1). In fact the ghost described by Hill is present for the entire spectrum, but the H $\alpha$  emission is the only part which is bright enough for its ghost to be visible above the ambient CCD background. Provided that we do not mistake it for real emission, this phenomenon does not cause much trouble. In principle however, it might contaminate measurements of diffuse emission in the Homunculus nebula. Therefore, in this document we further characterize this effect and we describe an algorithm that largely removes it.

Here we use the term “ghost” in the same context as Gull et al. and Hill, referring to the blurred images which in the case of H $\alpha$  emission appear approximately 100 pixels away in the decreasing row and increasing column direction from the sharp primary image (Figure 2). This is not to be confused with smaller scale instrumental effects such as the “railroad track” (which occurs on the scale of 20 pixels from the primary image) or the asymmetry in the cross-dispersed point-spread function (which occurs on scales  $< 5$  pixels).

It is very important to note that in this document we are discussing the H $\alpha$  ghost as it appears in the *reduced* STIS CCD data which has been interpolated and “rectified.” This is in contrast to the *raw* data which the work of Hill (2000) focuses on. Therefore, the information contained here is in most cases highly specialized to specific circumstances and may not be completely applicable to other STIS CCD data.

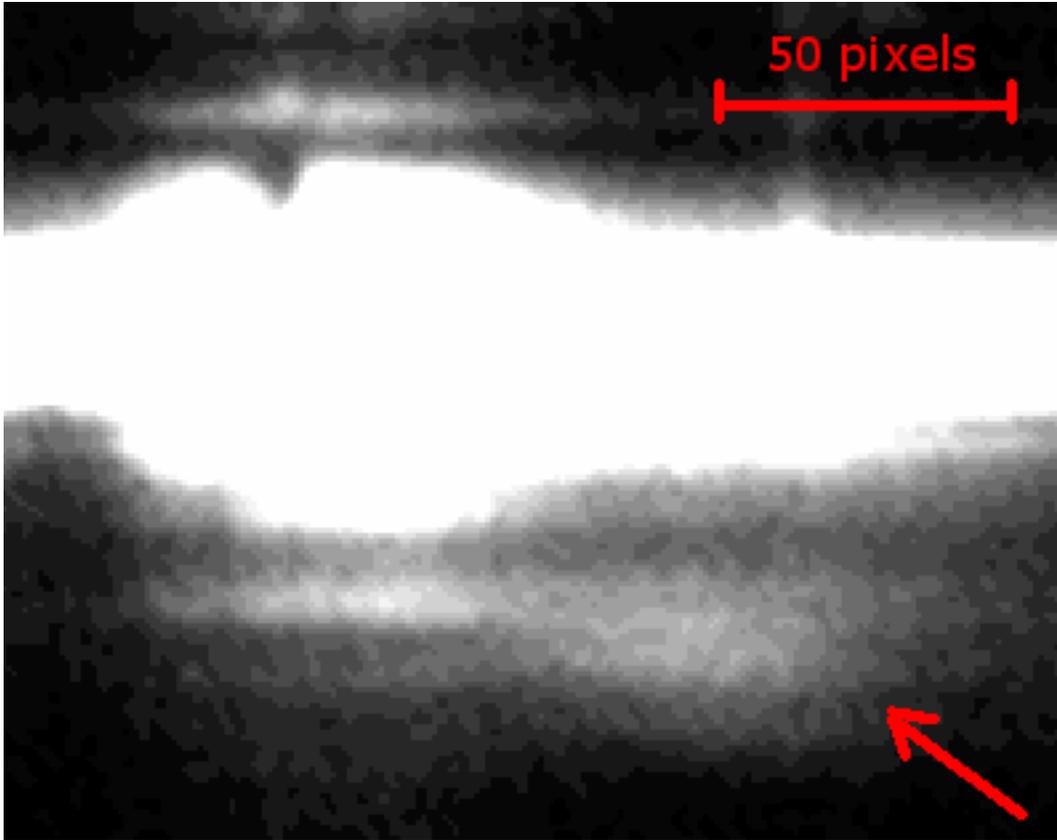


Figure 1. An example of an H $\alpha$  observation where the bright spot in the upper left is H $\alpha$  and the diffuse ghost appears below and to the right as indicated by the red arrow.

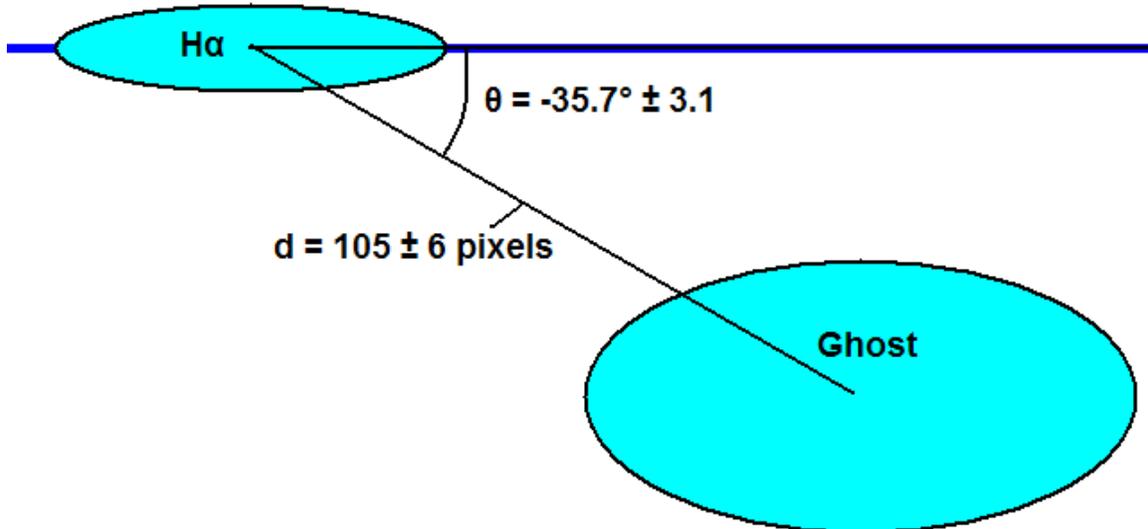


Figure 2. A sketch of the circumstances of the H $\alpha$  ghost in the STIS CCD data.  $d$  is given in reduced pixels which are half the size of original pixels in the raw data.

## 2. Characteristics of the H $\alpha$ Ghost

Figure 2 shows a schematic sketch of the H $\alpha$  ghost. The parameters were generated by measuring the relative positions of H $\alpha$  and its ghost in forty nine (49) observations of H $\alpha$  made for the Eta Carinae HST Treasury Project. The position angle of the ghost and its distance from the main image is entirely consistent with the measurements that Hill made in the same general part of the CCD where the H $\alpha$  emission consistently falls.

## 3. Modeling the H $\alpha$ Ghost

Initially, we tried to remove the ghost by modeling it as a complex of overlapping rings as described by Hill. However, this did not provide satisfactory results, probably because the pixels in the data we are working with have already been interpolated and rectified, transmuting and blurring the properties. Therefore, instead we took the approach of fitting the ghost with a two dimensional Gaussian. The general form (F) for a two dimensional Gaussian is:

$$g(r, c) = A(r - r_0)^2 + B(r - r_0)(c - c_0) + C(c - c_0)^2$$
$$F(r, c) = a \times \exp\{-g(r, c)\}$$

Where  $r$  is the row number and  $c$  is the column. We can eliminate one of the free parameters with the assumption (validated by Hill) that the axis of the ghost is aligned parallel to the CCD rows. So we use the following form:

$$g(r, c) = \left[ \frac{(r - r_0)^2}{2\sigma_r^2} + \frac{(c - c_0)^2}{2\sigma_c^2} \right]$$
$$F(r, c) = a \times \exp\{-g(r, c)\}$$

This model depends on five independent parameters:

$a$  = The amplitude (peak brightness) of the ghost

$r_0$  = The reduced CCD row of the center of the ghost

$c_0$  = The reduced CCD column of the center of the ghost

$\sigma_r$  = The FWHM of the ghost on the  $y$ -axis (along the reduced CCD rows)

$\sigma_c$  = The FWHM of the ghost on the  $x$ -axis (along the reduced CCD columns)

We modeled the ghost in forty nine (49) separate exposures in the Eta Carinae Treasury Project database where H $\alpha$  was not overexposed and there was significant signal in the ghost. These fits showed that the five independent parameters above have no discernable dependence on observation date or exposure length. The time dependant variation in the line profile for H $\alpha$  itself, independent of any property of the CCD or optical system, has an affect on the model parameters. Therefore, it was decided that any method to remove the ghost should attempt to fit the parameters for the ghost interactively rather than relying on static average values.

The following are a set of typical parameters for the ghost on MJD 50814. Be aware that these parameters are given for a 2D spectrum which has been interpolated into pixels half the size of an original CCD pixel. The value for “a” will scale with respect to the total flux in the H $\alpha$  emission and  $r_0$ ,  $c_0$ ,  $\sigma_r$ , and  $\sigma_c$  vary with respect to changes in the shape of the H $\alpha$  emission. Normally, as in this example, the total integrated flux of the ghost is only 0.5% to 1.0% the flux in the H $\alpha$  emission feature.

$$\begin{aligned} a &= 1.75\text{e-}14 \text{ erg/cm}^2/\text{s}/\text{\AA}/\text{row} \\ r_0 &= 418.37 \\ c_0 &= 455.47 \\ \sigma_r &= 30.91 \text{ reduced rows} \\ \sigma_c &= 13.28 \text{ reduced columns} \end{aligned}$$

### 3. Removing the H $\alpha$ Ghost

The code to remove the H $\alpha$  ghost from the STIS CCD data does so interactively starting with some assumptions about the shape and location of the ghost (as described in the previous sections of this document) and performing a regression analysis to determine the best fit parameters. Users should note that this automated method does a passable job of removing the ghost under most circumstances. However, better results can be achieved by using the manual overrides to tweak the parameters of the model to a more perfect fit. In particular, we suggest that you manually adjust the peak brightness (a) of the ghost model to achieve the best results.

The source code for the removal process is available for download on the Treasury Project web site (<http://etacar.umn.edu>).

#### References:

- Davidson, K. D. 2004, “Our Adopted Scheme for Subpixel Modeling”, Eta Carinae Treasury Project Technical Report #1, <http://etacar.umn.edu/treasury/publications/pdf/tmemo001.pdf>
- Gull, T., Lindler, D., Tennant, D., Bowers, C., Grady, C., Hill, R.S., and Malumuth, E., 2002, “The STIS CCD Spectroscopic Line Spread Functions” presented at the 2002 HST Calibrations Workshop. (S Arribas, A Koekemoer, and B. Witmore, eds.)
- Hill, R. S. 2000, “The Geometry and Approximate Correction of STIS CCD Window Ghosts,” STIS Post-Launch SMOV Report #063, (Goddard Space Flight Center: Greenbelt)
- Martin, J.C. 2004, “A Model of the Distribution of Scattered/Diffuse Light on the STIS CCD in Spectroscopic Mode”, Eta Carinae Treasury Project Technical Report #6, <http://etacar.umn.edu/treasury/publications/pdf/tmemo006.pdf>