9. Ghost Images

Description: Weak doughnut-shaped or fan-shaped artifacts near bright stars.

Cause: Internal reflections in CCD field-flattener lenses or in filters.

Each CCD has a plano-concave field-flattener lens made of MgF_2. A ghost arises when light passing though the lens is internally reflected from the surface near the CCD, to the surface opposite the CCD, and then back through the lens and onto the CCD. The field-flattener ghosts are always on the side of the star opposite the CCD center. The distance between the star and ghost increases as the distance from the CCD center increases; if D is the distance from the CCD center to the star, the ghost is between ~0.36D to ~0.41D from the star on the WF CCDs, and about ~0.25D to ~0.30D from the star on the PC. The total light in the ghost is determined by the refractive index of MgF_2; the ghost contains about 0.15% of the light in the main image. In the WFC the ghost is doughnut-shaped with diameter ~10 pixels, which is determined by the thickness of the lens which adds about 2 mm of defocus to the ghost optical path, and the camera f-ratio. The doughnut-shape is simply the shape of the defocussed OTA + camera relay pupil. On the PC the ghosts are only about 3 pixels in diameter due to the slower F-ratio.

The filter ghosts are fan-shaped (comatic), and are caused by reflections between different surfaces within a filter. The coma results from misalignment of the OTA pupil on the corrective camera relay secondaries for the ghost optical path. Their location varies from filter to filter, but for a given filter the offset from the star to the ghost (in sky coordinates) will be constant over the field of view. They tend to be stronger for narrow band filters, which are interference filters with little internal absorption. The strength of the ghost varies from filter to filter, but is generally less than 1%. Multiple ghosts can be seen, which are due to repeated internal reflections.

Examples: Figures 9.1 through 9.3 show a variety of field-flattener ghosts. In all cases the star is located on a line from the CCD center and through the ghost image.

Figure 9.4 shows a filter ghost for the F502N filter. The first order ghost contains about 2% of the total starlight, while the second order ghost contains about 0.04% (0.02^2).

Impact: Will hamper searches for faint objects near bright ones.

Correction: The field-flattener ghosts can be removed when combining multiple images of the same field which are observed with large (>100 pixel) position dithers. See Section 14. (Note, however, that optical distortion will complicate analysis of images with large dithers.) The filter ghosts can be removed when combining images of the same field which are observed at different spacecraft roll angles (ORIENTs).

Prevention: Observe with position dithers, or different spacecraft roll angles, to allow removal of artifacts during analysis.

Figure 9.1. Example of field-flattener ghost in WF4. Image shows entire CCD.

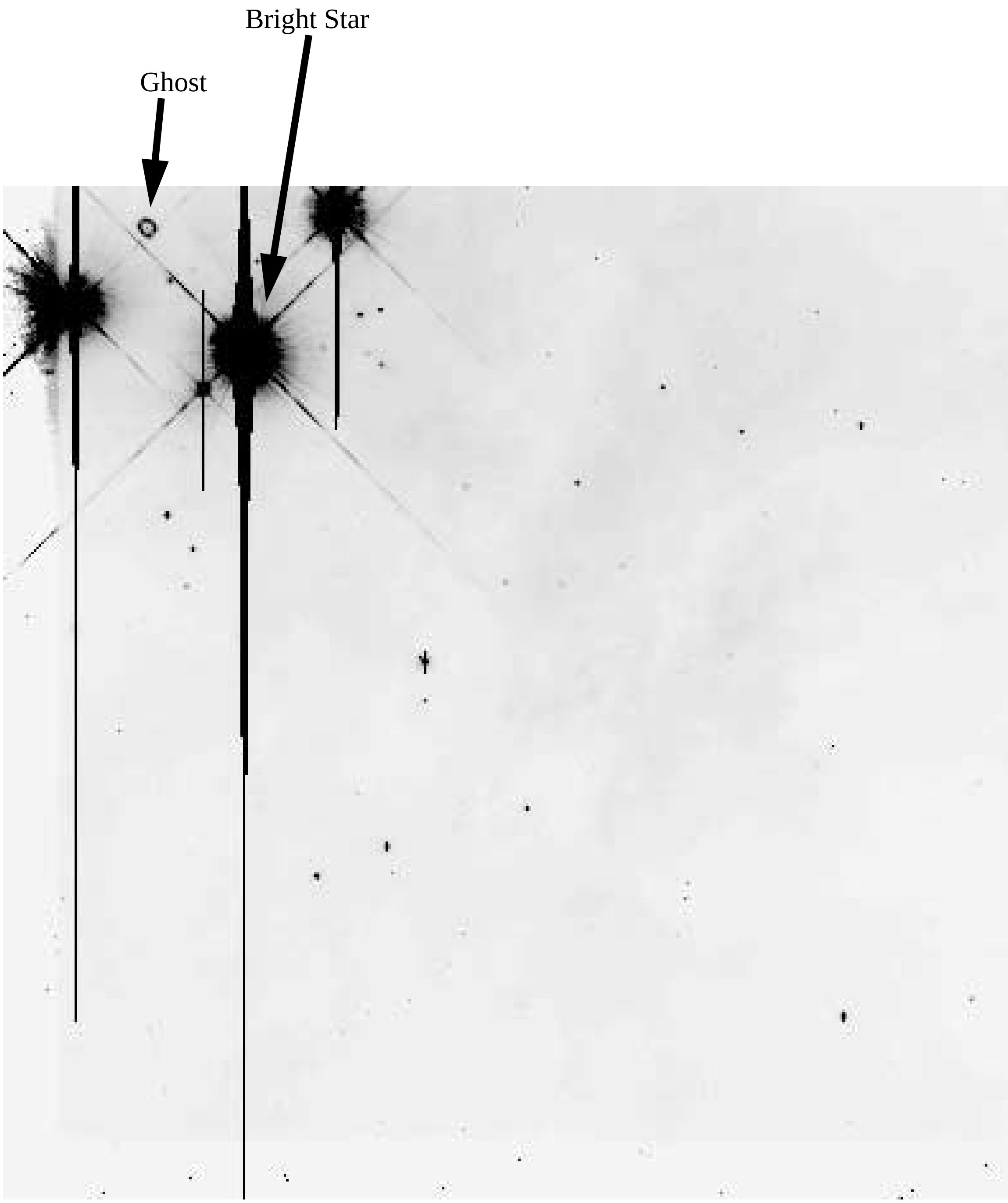

Figure 9.2. Example of field-flattener ghost in WF2. Image shows entire CCD.

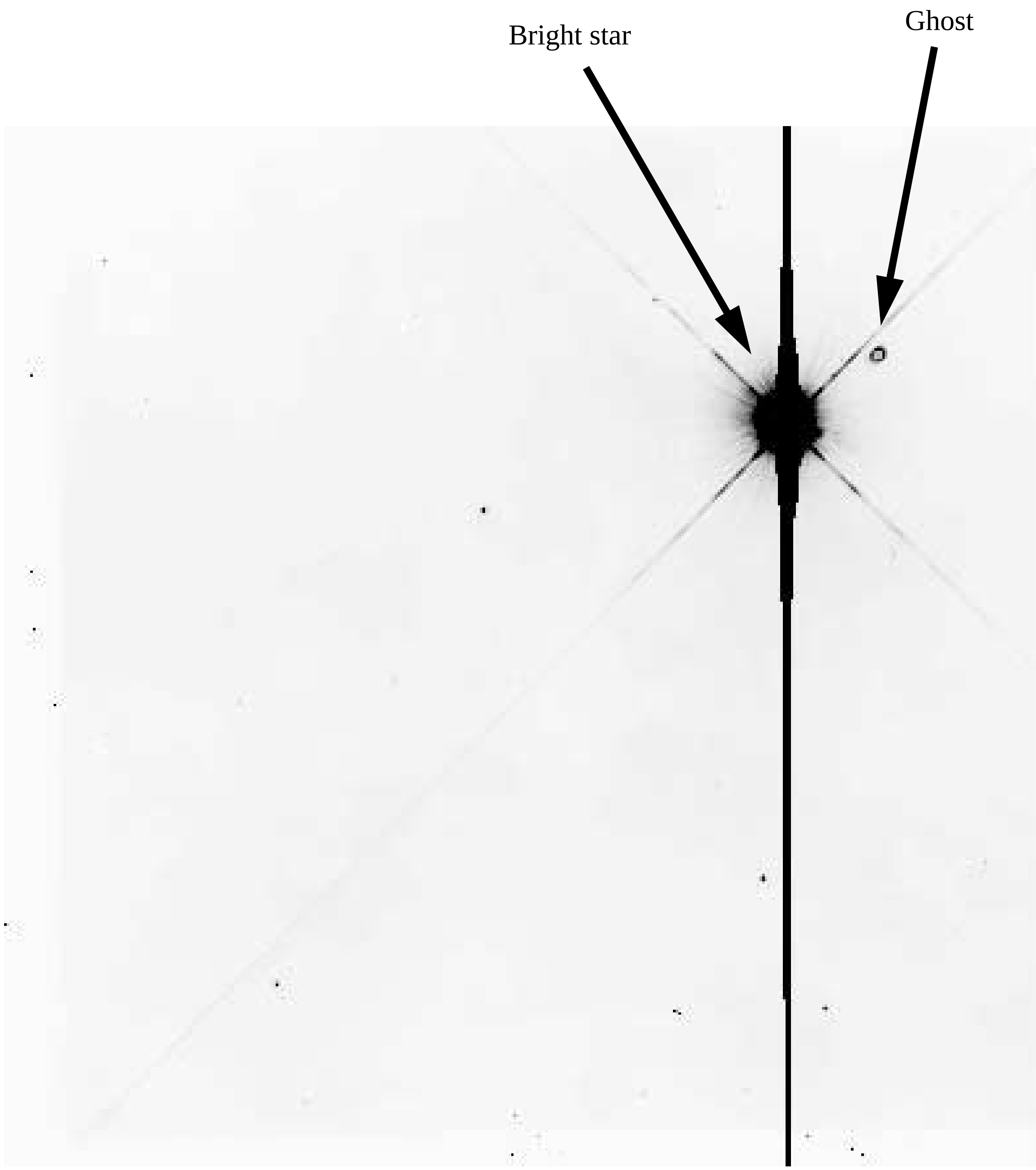

Figure 9.3.a. Another field-flattener ghost on WF4. Here the star contains about 7×10^6 electrons. Note that the ghost image always lies on a line which passes through the CCD center, through the star, and finally through the ghost. Image shows entire CCD.

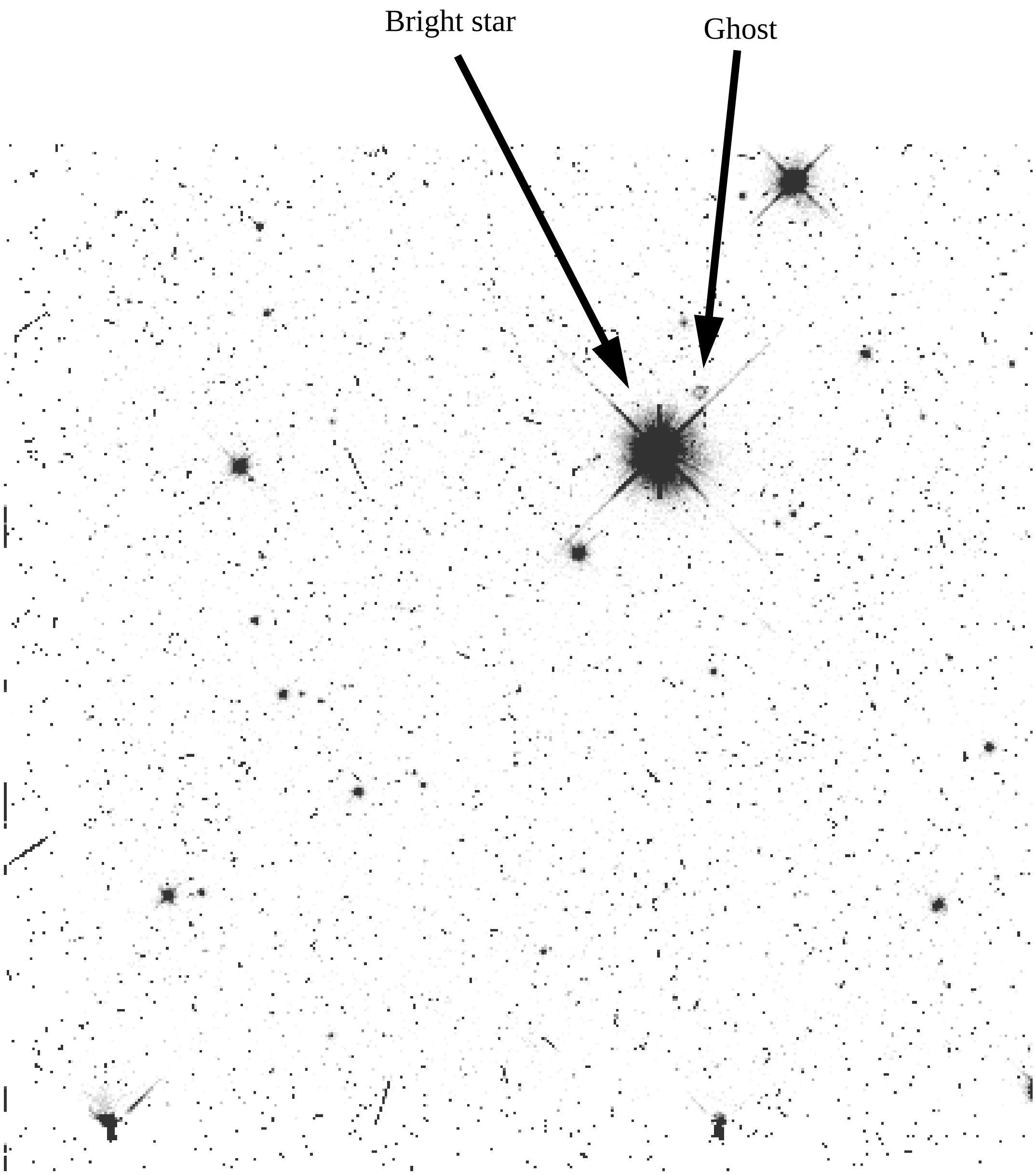

Figure 9.3.b. Detail of field-flattener ghost on WF4 in Figure 9.3.a.

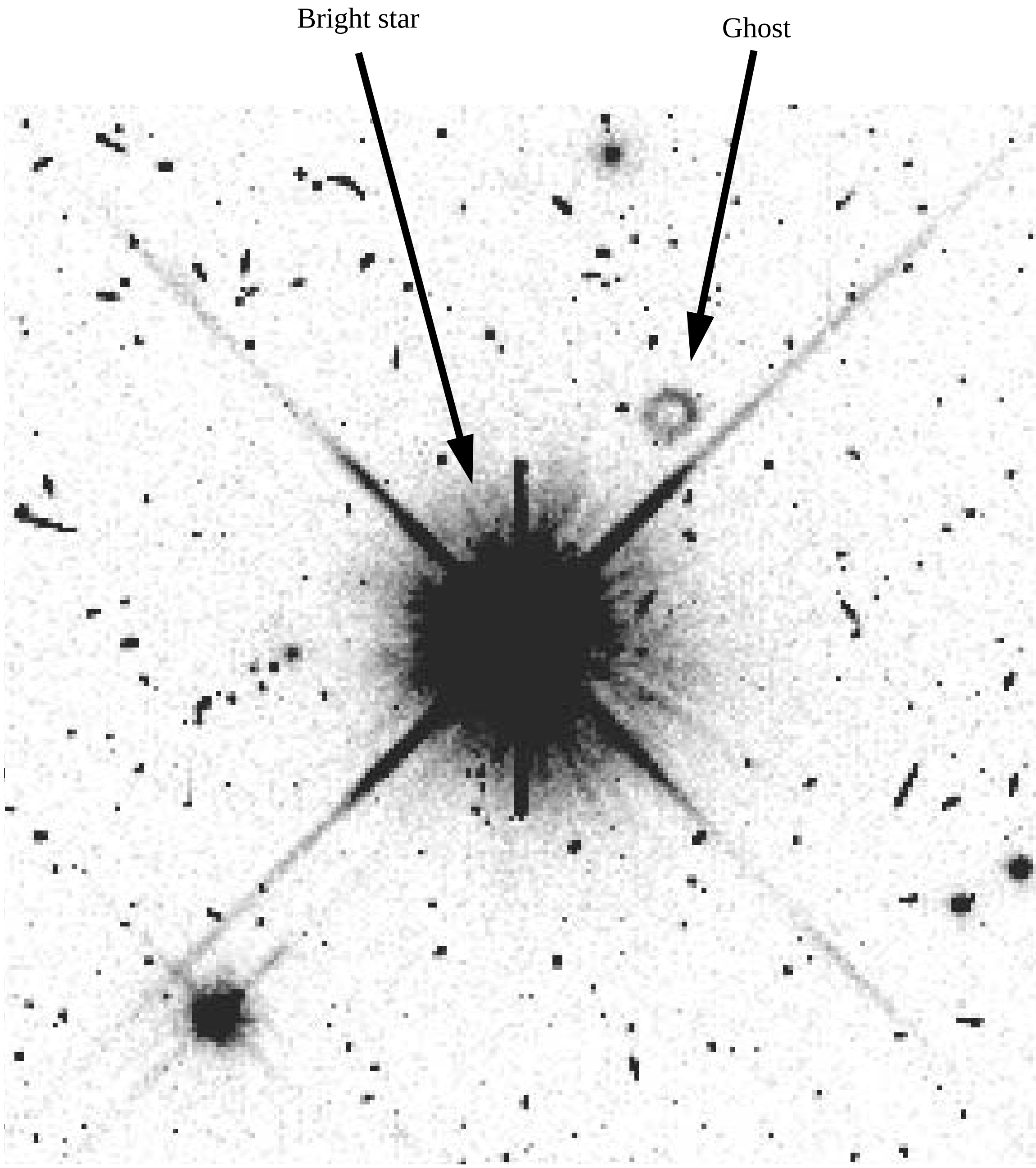

Figure 9.4. Example of filter ghosts in F502N filter. Intensity scale is logarithmic. The star contains about 4 x 10^8 electrons. Of this about 2% are in the first-order ghost, and 0.04% are in the second-order ghost.