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Ghost Images in Schmidt CCD Photometry

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Abstract The wide field of the Schmidt telescope implies a greater chance of the field containing bright objects, and the presence of a corrector lens produces a certain type of ghost images. We summarize and confirm the features of such ghost images in Schmidt CCD photometry. The ghost images could be star-like under special observational conditions. The zenith distance of the telescope, among other factors, is found to correlate with different patterns of the ghost images. Some relevant issues are discussed and possible applications of our results are suggested.

Key words: instrumentation: detector — techniques: photometric — stars: imaging

1 INTRODUCTION

Ghost images are a common but not widely noted phenomenon in imaging technique with optical telescopes, especially for the large field observation with Schmidt telescopes. Ghost images in photographic plate photometry were investigated by the U. K. Schmidt Telescope Unit (UKSTU) and were classified into five cause-related types: Emulsion-corrector, Filter-corrector, Corrector, Filter and Spike ghosts. Ghost images in spectral observations with modern CCD technique were discussed by Wynne et al. (1984). In this paper, we concentrate on ghost images in CCD photometry with Schmidt systems, and specifically on that particular type where the ghost is located symmetrically opposite to the bright primary, the type labelled as emulsion-corrector ghost for the photographic case described in the UKSTU Handbook (Royal Obs. 1983).

In general, the pattern of ghost image is quite distinguishable from real stellar images, according to both the literature (UKSTU Handbook 1983; Marx & Pfau 1992) and practical experiences. However, detailed analysis of the CCD photometric images taken with the 60/90 cm Schmidt telescope of National Astronomical Observatories, Chinese Academy of Sciences (NAOC) shows that there are some other patterns which are quite different from the 'ordinary' pattern, the open triangle, that are known to the NAOC Schmidt observers. Espe-

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cially, some ghost images could be of the same pattern as stellar images under certain observing conditions. Ignorance of the existence of ghost images may lead to false detections of optical transients (OTs), such as optical afterglows of gamma-ray bursts, splittings of comets, asteroids, comets, or supernovae etc.

All the observations mentioned in this paper were made with the NAOC 60/90 cm Schmidt telescope plus a 2048 × 2048 CCD (Chen 1998).

2 FEATURES AND CONFORMATIONS OF GHOST IMAGES

2.1 Features of Ghost Images

A quite obvious characteristic of ghost images is that a ghost image and its bright primary are centrally symmetric about a fixed point, near the center of the CCD frame. Explanation of this phenomenon could parallel the explanation for the case of photographic photometry described in the UKSTU Handbook (Royal Obs. 1983), that is, the light forming the primary image is reflected at the CCD to the main mirror, then reflecting at the mirror to corrector lens, where it is partially back-reflected to the main mirror again. Finally, the main mirror reflects it back down onto the CCD to form the ghost image. Therefore, the ghost image and its primary image are symmetric with respect to the optical axis according to the law of reflection. The center of symmetry corresponds to the intersection of the optical axis on the CCD surface, which may not coincide with its physical center. For the 2048 × 2048 CCD on the NAOC Schmidt system, the center of symmetry is found to be at at (1013 ± 1, 980 ± 3), from statistics of observations made in November 1999. We may expect this position will not change unless the optical system undergoes adjustment (such as coating of the main mirror).

The ghost image is about 7 to 8 magnitude fainter than the primary image but the magnitude difference is not linear with the brightness of the primary, see Table 1. Therefore, ghost images are only visible for the brightest stars and/or under long exposures. The magnitudes of the primary stars are taken from USNO-A2.0 Catalogue (Monet et al. 1998) directly, while the magnitudes of the ghost images are obtained with aperture photometry adopting magnitudes of reference stars from the same catalogue. The error for the derived Δm could be greater than 0.5 mag.

Table 1 Magnitude of Ghost Image and Its Primary

$m_{\rm prim.st.}$	3.6	5.6	6.2	6.8	7.4	8.3	8.8	10.4	10.9
$m_{\rm ghos.im.}$	10.6	13.4	13.1	13.7	14.8	15.5	16.3	17.3	18.3
Δm	7.0	7.8	6.9	6.9	7.4	7.2	7.5	6.9	7.4

The CCD images also show that very bright stars are often accompanied by aureole (corrector ghost and halo as described in the UKSTU handbook (Royal Obs. 1983)), and there are also aureoles around ghost images too. The brighter the star is, the more distinct is the aureole. The ghost image aureoles are concentric, usually with three sharp boundaries at radii 1.65 mm, 4.32 mm and 5.48 mm from the image center.

2.2 Classification of Ghost Image Conformations

Ghost images appear in different shapes under different conditions (airmass, seeing, focus distance etc.), and can be divided into the following four types (Fig. 1):

a. Open triangle, which is the most common pattern and is well-known to the NAOC Schmidt observers. The triangle deforms slightly with changing observing conditions.

b. Trifurcate, which can be further divided into sub-types, trifolium, trifoliate windmill, and so on.

c. Solid triangle.

d. Point source, which looks exactly the same as a stellar image and cannot be superficially distinguished from the latter (Fig. 2). In practice, observers could easily misinterpret this kind of ghost images as real objects.

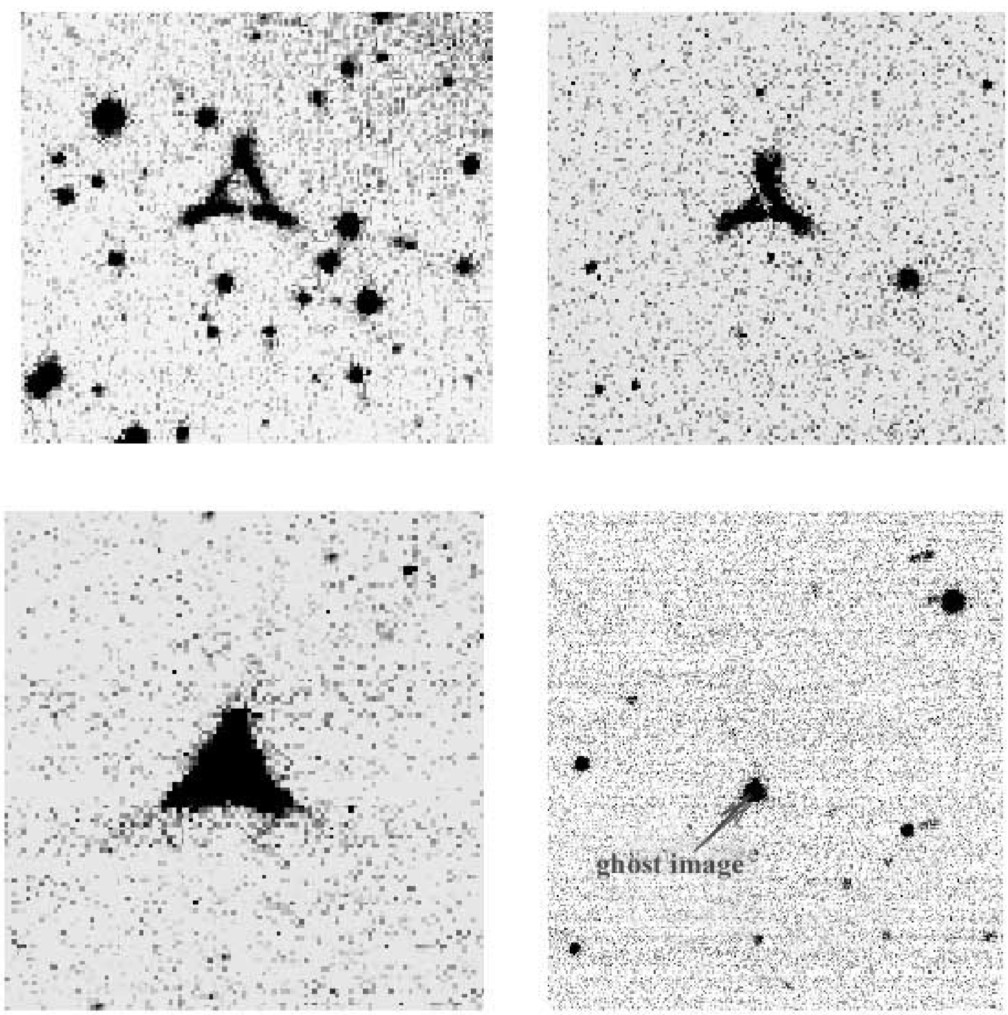

Fig. 1 Classification of ghost image conformations. Open triangle upper-left, Trifurcate upper-right, Solid triangle lower-left, Point source lower-right.

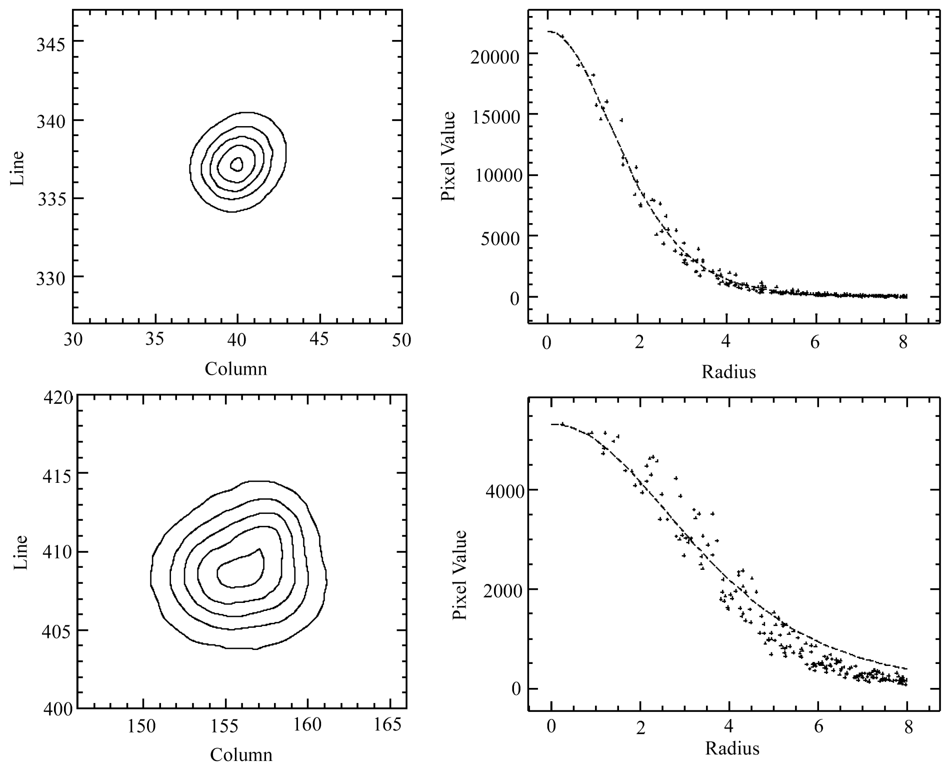

Fig. 2 Contour plots (left) and radial profiles (right) of real star (upper) and ghost (lower).

3 EXPERIMENTAL OBSERVATIONS

3.1 Influence of Filters

Observations show that all four types of ghost image mentioned above appear with equal probabilities in images taken through different filters, or with no filters at all. Thus, ghost images are independent of filters. Our observations referred to in this paper were usually taken with the BATC i-filter (Fan et al. 1996; Zheng et al. 1999) unless specifically noted.

3.2 Brightness and Location of The Bright Primary

Observations show that under the same observational condition no matter where the bright primary is located on the CCD, the shape of the ghost image is nearly always the same and does not vary with its position on the the CCD surface. The conformations are not influenced by the brightness of the primary either.

3.3 Influence of the Pointing of the Telescope

Observations show that the shape of the ghost image changes when the telescope points to different directions. When the telescope points near zenith ($1 <$ airmass < 2), the shape is that of a trident, or sometime an open triangle, and this is so even under very poor seeing condition. There is a transition from the trident to a solid triangle when the airmass ≥ 2. As the airmass increases, the three "prongs" get shorter and shorter, to become a typical triangle when the airmass approaches 3. The image then changes gradually from a solid triangle to a round point as the telescope points still lower ($3 <$ airmass < 4). After airmass > 4 the ghost remains round; however, it can still be distinguished from a real star because its shape is slightly irregular. Eventually, when the telescope points to near horizon (airmass > 5), the ghost appears as a regular roundish dot, remaining indistinguishable from nearby stellar images.

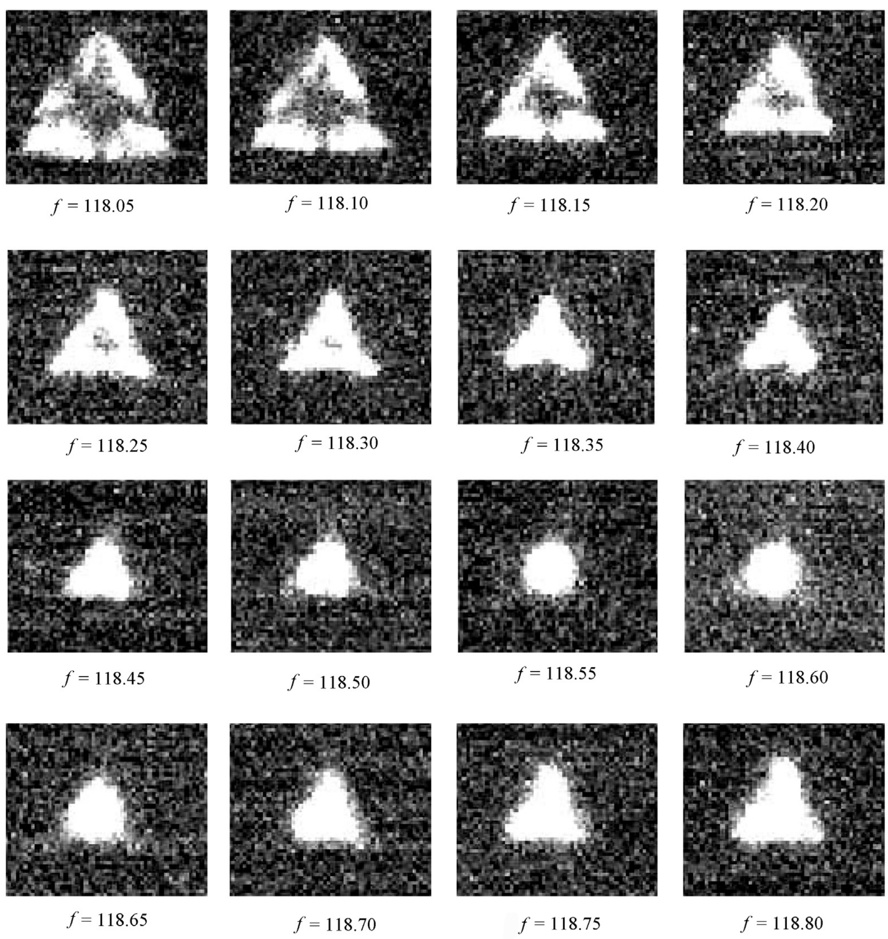

Fig. 3 Out-of-Focus Ghost images.

3.4 CCD at an Out-of-focus Position

When the pointing of telescope is not too low, ghost images assume the most common shape of open triangle when the CCD is at the normal focus and the distance between CCD and the main mirror is 118.3 cm. Moving the CCD backward and forward along the optical axis produces out-of-focus images, and alters the shape of the ghost images completely (Fig. 3).

As the CCD-focus distance increases from 118.30 cm to 119.00 cm, the shape of ghost image changes from open triangle to trifurcate, then to point source. Near 118.55 cm, the ghost image looks exactly like a real star. Increasing the distance further changes the shape continuously to solid triangle. When the distance is larger than 118.95 cm, the ghost image retains its shape but becomes blurred. All the four types behave in this way. When we decrease the CCD-Focus distance, the ghost remains in the shape of a triangle, but after 118.16 cm it becomes blurred and indistinct.

4 DISCUSSION

4.1 Shape of Ghost Image

4.1.1 Trigonal shape of ghost image

We like to point out that the NAOC Schmidt corrector lens is fixed by three bolts, located in an equilateral triangle. A possible explanation of the trigonal shape of the ghost image, we suspect, is that the corrector lens must sag under gravity at certain zenith distance, and the tiny distortion of the corrector lens then produces out-of-focus ghost images with shapes that are consistent with the support structure of the corrector lens. Since the light forming the ghost involves an additional reflection in the corrector lens, any distortion in the corrector affects more the ghost than the primary, hence the ghost may appear irregular when the primary still appears normal.

4.1.2 Star-like ghost image

As stated in Section 3.4, the various shapes of the ghost image are related to the extent the image is out of focus. Considering that the ghost image is formed differently from the real stellar image, the focus for the ghost should deviate from the focus of the system. Now the corrector lens is designed to eliminate the aberrations at the system focus, especially for parallel rays, so an out-of-focus ghost image cannot be improved by the corrector lens, hence its irregular shape. If we adjust the position of the CCD plate to the focus for the ghost image, then the latter will be star-like. In Section 3.3, it was noted that the ghost appears star-like when the telescope points at large zenith distance, for then the corrector lens is almost vertical and so does not sag, and the ghost image focuses on the image plate.

4.2 Shape of Real Star Image

It should be noted that the image of a real stellar object changes greatly from a clear image to a diffuse one when the distance between the CCD and main mirror is varied. But the change is totally different from the case of the ghost image discussed in Section 3.3. Unlike the ghost image, the shape of the real star image is not changed when the telescope points in different directions.

4.3 Relevant Problems with CCD Photometry

When a new object or a new feature is found in a CCD observation, it is preferable to first exclude the possibility of it being a ghost image. This can easily be achieved by looking at the opposite position on the other side of the center of the field to see whether there is a bright object there.

To avoid ambiguity, we should take at least two exposures of the same field with the telescope shifted slightly between the exposures: any ghost image will then be shifted in the opposite direction to the real images. For reliable detection of moving objects like asteroids and comets, it is necessary to take at least three exposures of the same field, and it is then useful to move the telescope not in the same straight line between the exposures, so that we can distinguish ghosts from bad pixels easily. Dividing one long exposure into three shorter ones is also helpful for cosmic-ray rejection and tracing, though it increases the influence of read-out noise.

It is quite useful, especially in the case of photometry, to keep in mind of the influence of ghost images when choosing the center of the observation field. We should avoid choosing the field center in the middle of a bright object or a target, or putting a bright target in the middle of the field.

4.4 Suggestions for Possible Applications

4.4.1 Location of optical axis

By measuring the coordinates of both the ghost images and their primaries, we can determine precisely the position of optical axis on the CCD surface. Repeating this procedure from time to time monitors any change in time of the CDD-optical axis separation.

4.4.2 Reflectivity of main mirror

From the account in Section 2.1, it can be seen that the intensity ratio of the ghost and its primary depends on the square of the reflectivities of the main mirror and the corrector lens, and on the square of the transmissivity of CCD quartz window. If we assume that both the reflectivity of corrector lens and the transmissivity of quartz window of CCD are constant, then any time variation of the reflectivity of the main mirror (which may be caused by the decay of surface coating) can be monitored by a continual measurement of the ghost/primary intensity ratio.

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References

Chen J. S., 1998, In: McLean B. J. et al., eds., Proc. IAU Symp. 179, New Horizons from Multi-Wavelength Sky Surveys., Baltimore: Kluwer, 123

Fan X., Burstein D., Chen J.-S. et al., 1996, AJ, 112, 628

Marx S., Pfau W., 1992, Astrophotography With the Schmidt Telescope, Cambridge: Cambridge Univ. Press

Monet D., Bird A., Canzian B. et al., 1998, USNO-A2.0, Washington: US Nav. Obs.

UKSTU Handbook, 1983, Royal Observatory, Edinburgh

Wynne C. G., Worswick S. P., Lowne C. M., Forden P. R., 1984, Observatory, 104, 23

Zheng Z. Y., Shang Z. H., Su H. J. et al., 1999, AJ, 117, 2757