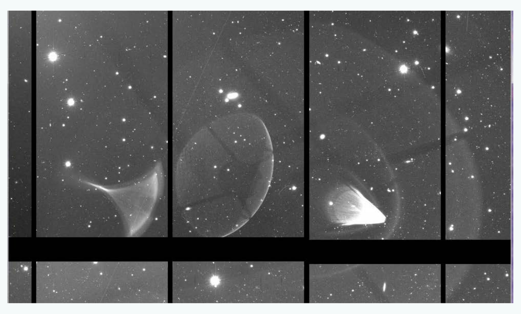
Ghost Busters: Subaru/HSC Ghost Analysis&Removal (1) Cometary Ghosts



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Abstract

We have investigated the optical ghosts generated on the images of Hyper Suprime-Cam (HSC). In this presentation, we focus on the cometary-shaped (or jellyfish-shaped) ghost which is one of high intensity ghosts. The ray tracing based on the as-built model of HSC optics shows that the cometary ghosts are caused by the reflection of the filter and the 4th lens element (G4) of the wide-field corrector, in the way that (1) the incident light is reflected at either the entrance or exit surface of the filter, (2) then reflected again at the surface of the M1 side (S1) of G4 and (3) finally reached to the detector on the focal plane. Because of the concave shape (seen from the focal plane) of the G4-S1, the convergent light is concentrated at near the focal plane and results in the high-intensity ghost. Using the optics model, the position of the ghost is estimated from the position of the bright star which generates the ghost. We show how well the optics model reproduces the position and the shape of the ghost. By masking the ghost on the individual image frame, we show that the ghosts can completely be eliminated from the coadded image using real HSC images.

1. Introduction

Hyper Suprime-Cam (HSC) is a powerful CCD camera on the Subaru Telescope which covers the 1.5 degree diameter field of view. Due to its wide-field coverage, birght stars are likely to be found in the field of view and they generate various type of ghosts, which affect the study of faint objects and low surface brightness features. Fig. 1 (left) shows an example; Arcturus (αBoo), 0th mag star located at 0.25 degrees from the optical axis, generates multiple ghosts. Some of them are compact-shape and high-intensity and those ghosts generated by ~8 mag stars (~10 mag stars for narrow band images) are still visible in the HSC images.

We carried out the ray tracing based on the as-built model of HSC optics and identified the pair of reflecting surfaces which generate the ghost. Fig. 1 (right) summarizes the result of our ray tracing. We found that all the ghosts are well reproduced by our ray tracing and, surprisingly, reflections on 4 planar surfaces are required to explain some ghosts. The conclusion here is that the ray tracing is necessary to understand the nature of the ghosts.

In this poster, we present the method to remove the cometary-shaped (or jellyfish-shaped) ghost which is one of high intensity ghosts.

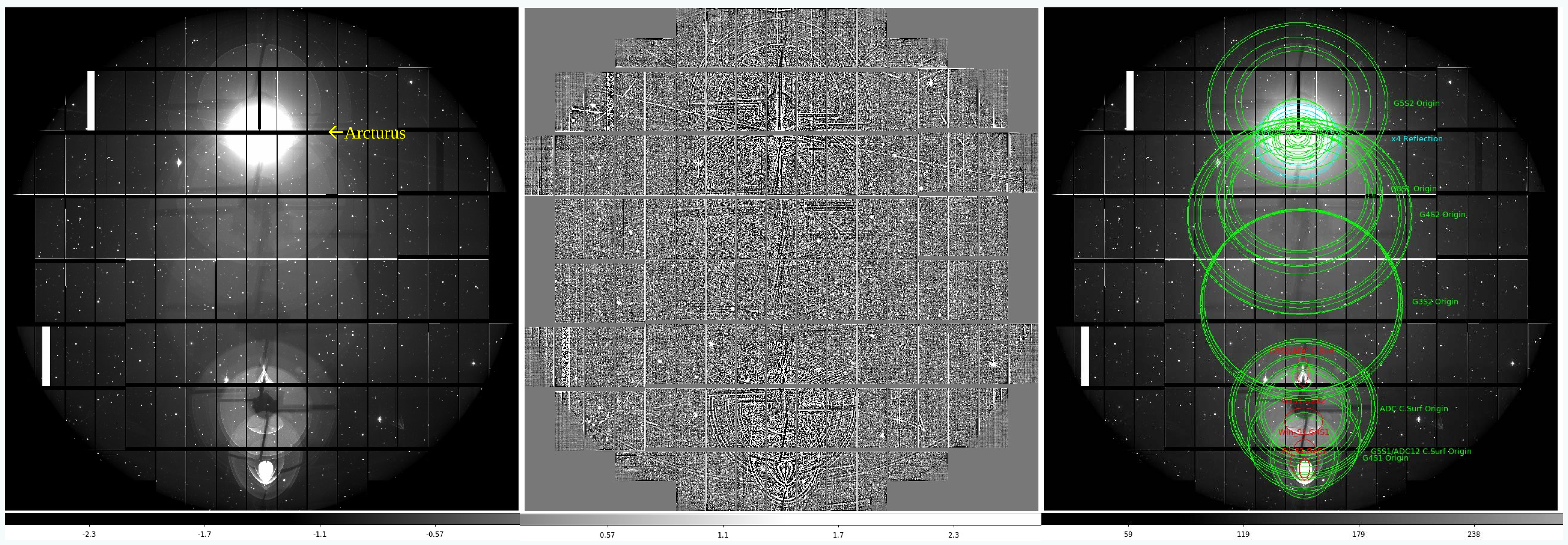

Fig.1: (Left): Off-focused image of Arcturus in HSC-i band. (Middle): Edge detection filtered image of the left figure reveals the shape of the ghosts down to faint level. (Right): ghosts reproduced by ray tracing. High-intensity ghosts are marked in red, 4 reflection ghosts are marked in cyan. Note that the shape of the some ghosts is complicated and is not always well represented by ellipse.

2. Cometary Ghosts

Among the various type of ghosts, the cometary ghost is the one with highest intensity except for those generated around the ghost source stars generated by the reflections of planar surfaces located near the focal plane (e.g., filters, window and CCD). This ghost is observed in significant fraction of HSC images, in particular images obtained with narrow-band filters. Its shape changes according to the position of the ghost source star on the focal plane.

The cometary ghosts are generated by the reflection of the filter and the 4th lens element (G4) of the wide-field corrector, in the way that (1) the incident light is reflected at either the entrance (primary mirror [PM] side, S1) or exit (CCD side, S2) surface of the filter, (2) then reflected again at the surface of the M1 side (S1) of G4 and (3) finally reached to the detector on the focal plane. Fig. 2 shows the layout of optical components at the prime focus (the wide-field corrector [G1-G5], filter, window and CCD) and the ray tracing for the incident beam from 0, 0.25 and 0.5 degree. The resultant ghosts are generated at the opposite side on the focal plane, crossing the optical axis. Because of the concave shape (seen from the focal plane) of the G4-S1, the convergent light is concentrated at near the focal plane and results in the high-intensity ghost. The shape of the cometary ghost at a fixed position on the focal plane is different among filters, since (1) the position of the filter along the optical axis and the thickness of the filter are different among filters, and (2) the major reflection surface (either S1 or S2) is not controlled and dependent on the filter (This is why as-built optics model is required for the analysis).

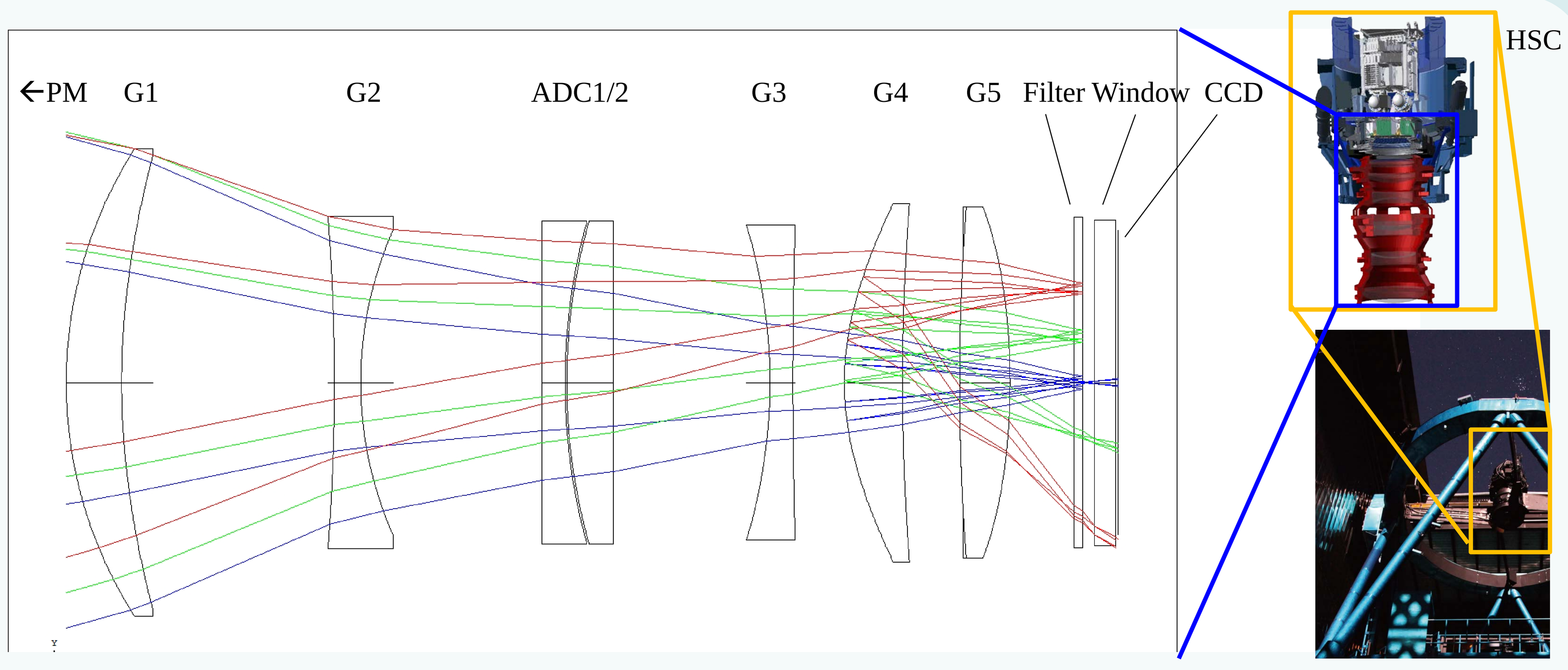

Fig. 2: The ray tracing of cometary ghosts. The incident beam from 0, 0.25 and 0.5 degrees are plotted in blue, green and red.

3. Removal Method

The method to remove the ghost is very simple as is described below.

1. Calculate the predicted position (Pos) and size (Rad, radius of the circle enclosing the ghost) of the ghost as a function of the angle (θ) between the ghost source star and the optical axis using the optics model.
2. For a certain exposure (visit), calculate θ from the coordinates of the ghost source star and the optical axis on the sky and obtain the predicted position and size using the relation obtained in 1.
3. Mask the relevant pixels in the exposure according to the prediction by 2.
4. Coadd masked exposures (Note that this method assumes that the dataset is composed of dithered exposures with appropriate intervals).

Figs 3 show the predicted position and shape of the ghosts as well as Pos (θ) and Rad (θ) for NB0656 (Halpha) filter. Note that Pos (θ) and Rad (θ) are filter dependent.

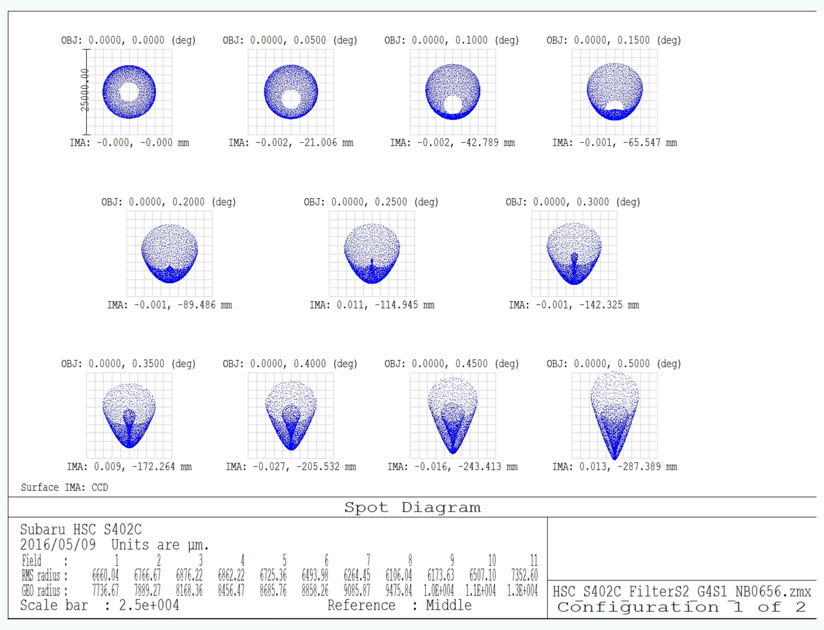

Fig. 3-1: The predicted shape of the cometary ghost as the function of the angle (θ) between the ghost source star and the optical axis for NB0656 (Halpha) filter. The obscuration of the prime focus structure is included in the calculation.

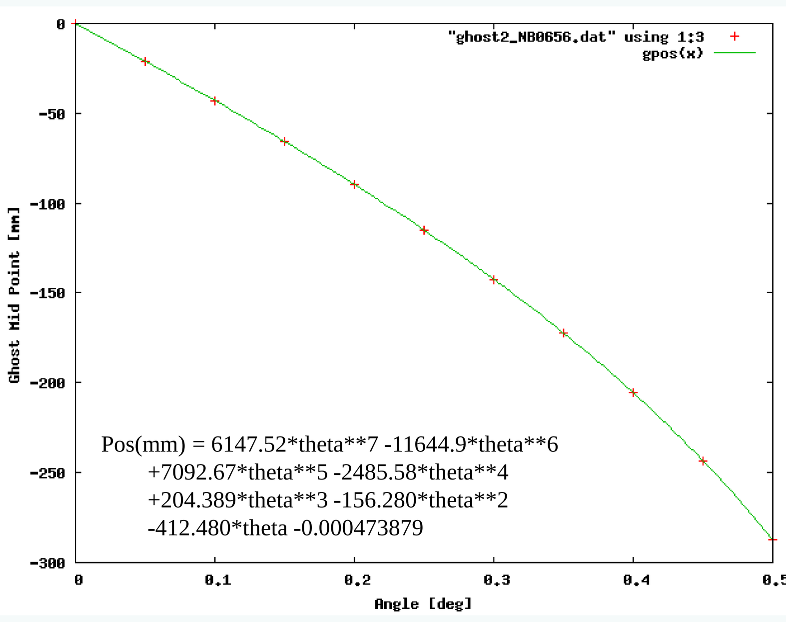

Fig. 3-2: The predicted position of the ghost as a function of θ, Pos(θ) for NB0656 (Halpha) filter. The data points are fitted with 7th order polynomial.

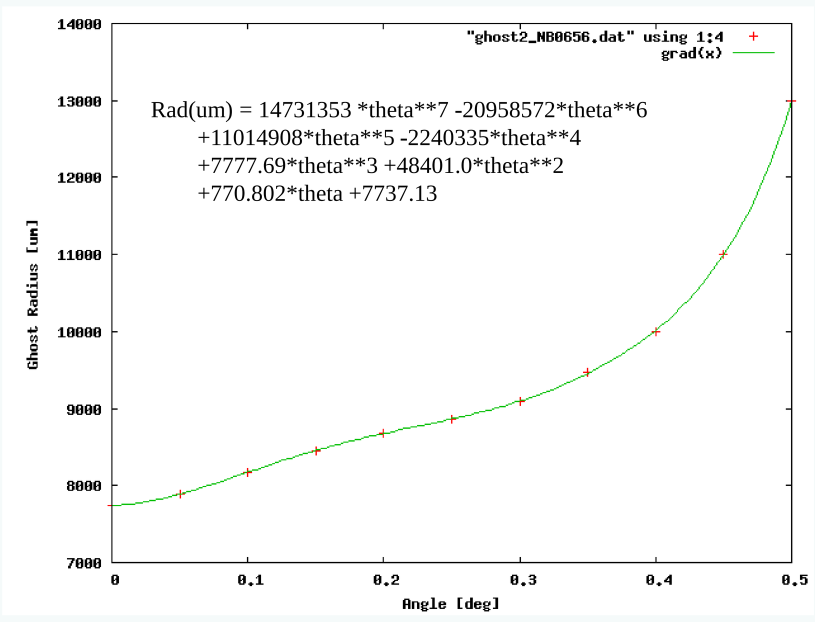

Fig. 3-3: The predicted size (radius of the circle enclosing the ghost) of ghost as a function of θ, Rad(θ) for NB0656 (Halpha) filter. The data points are fitted with 7th order polynomial.

4. Application to the Real Images (NGC6822 NB0656-band image)

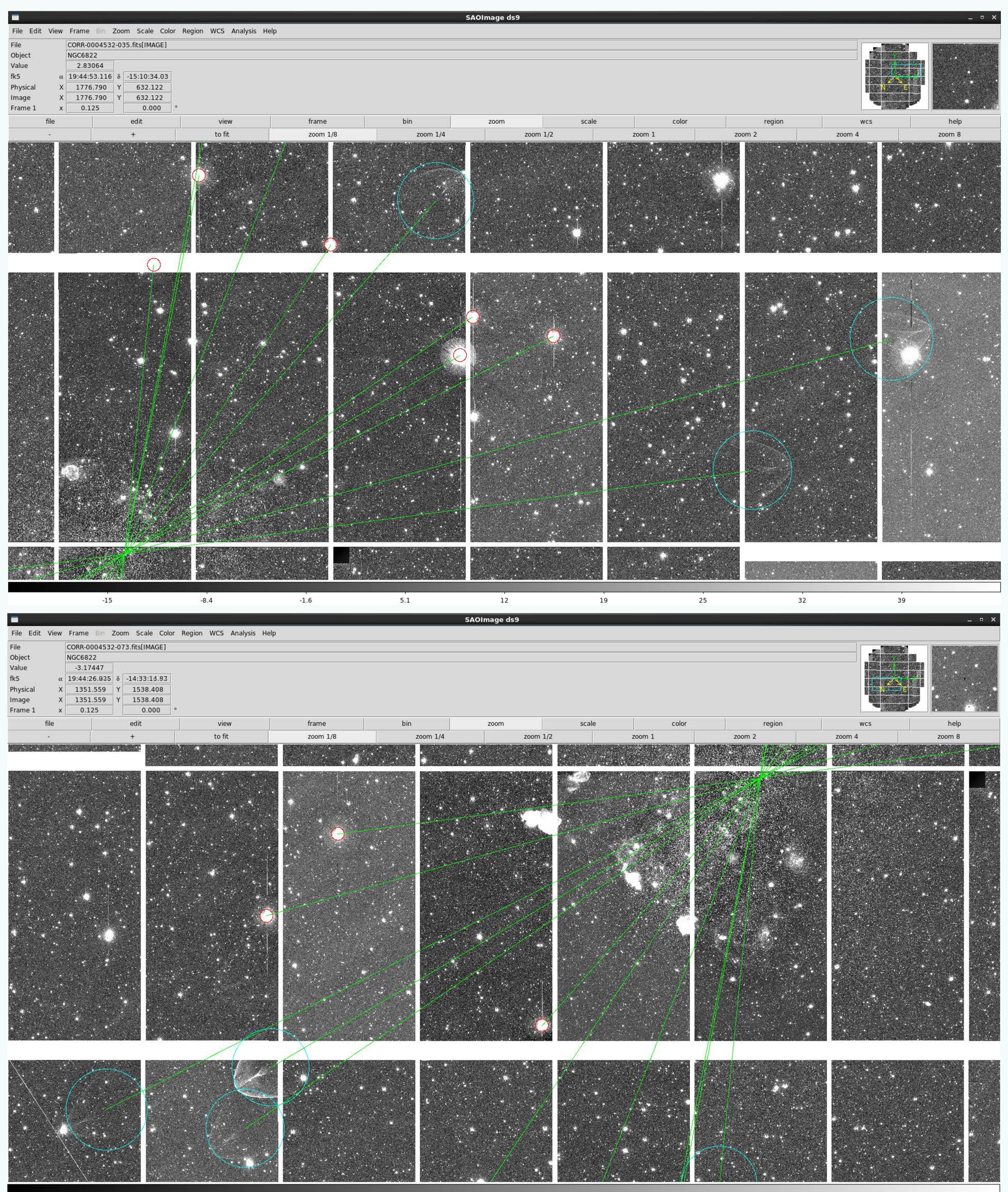

Fig. 4-1: Positions of ghost source stars (red) and predicted ghosts (cyan). The coordinates of ghost source stars (Rmag<10) are calculated from PPMX catalog (Roeser+ 2008), taking the proper motions into account. The method predict the positions and sizes of the ghosts very well.

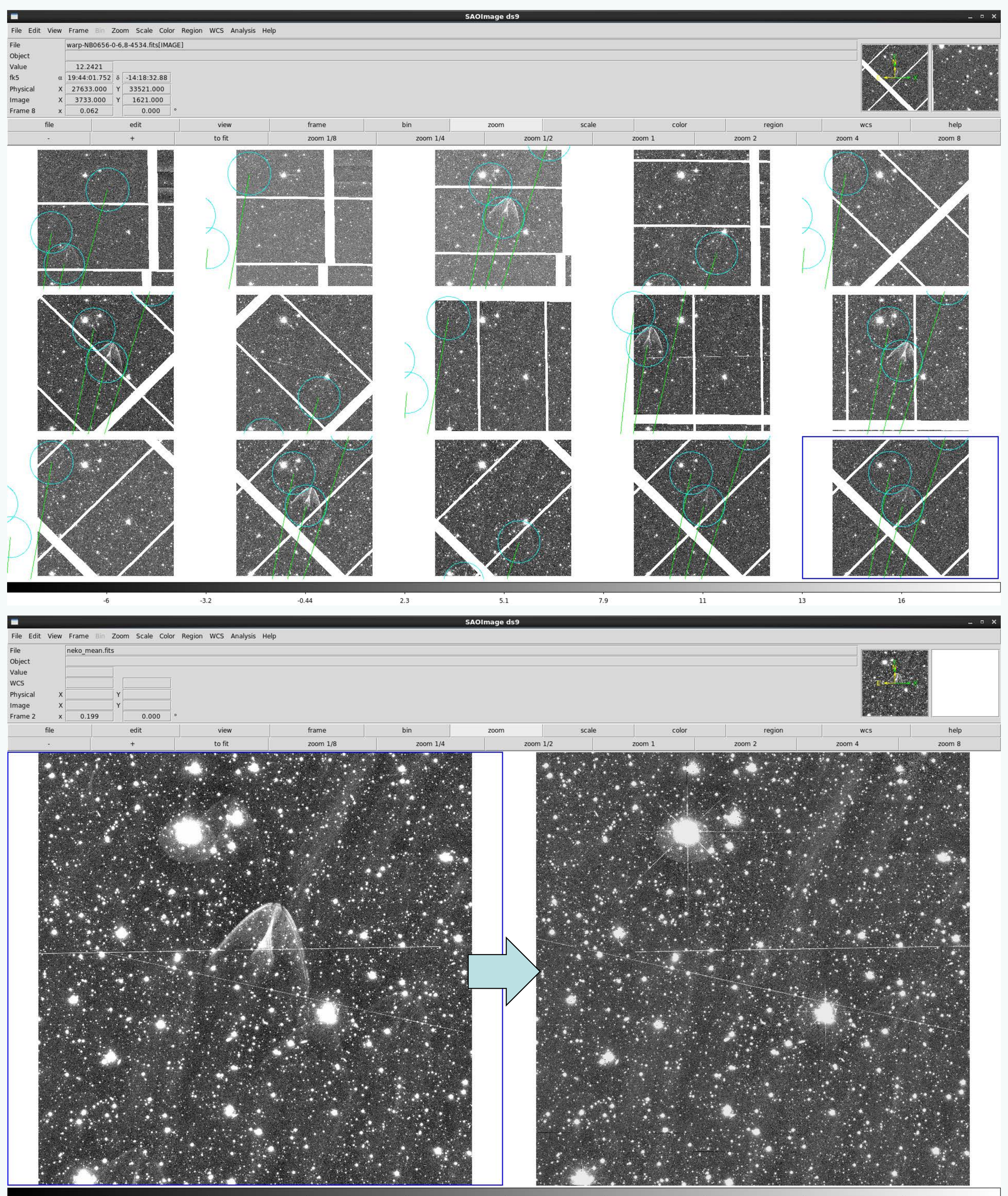

Fig. 4-2: (top): The predicted positions and sizes of ghost for 15 exposures in a certain position (patch 6,8; 4200x4200pix). The estimation is valid for different dither and position angle exposures. (bottom): Coadded image (clipped-mean stacking) of 15 exposures before the ghost removal (left) and after (right).

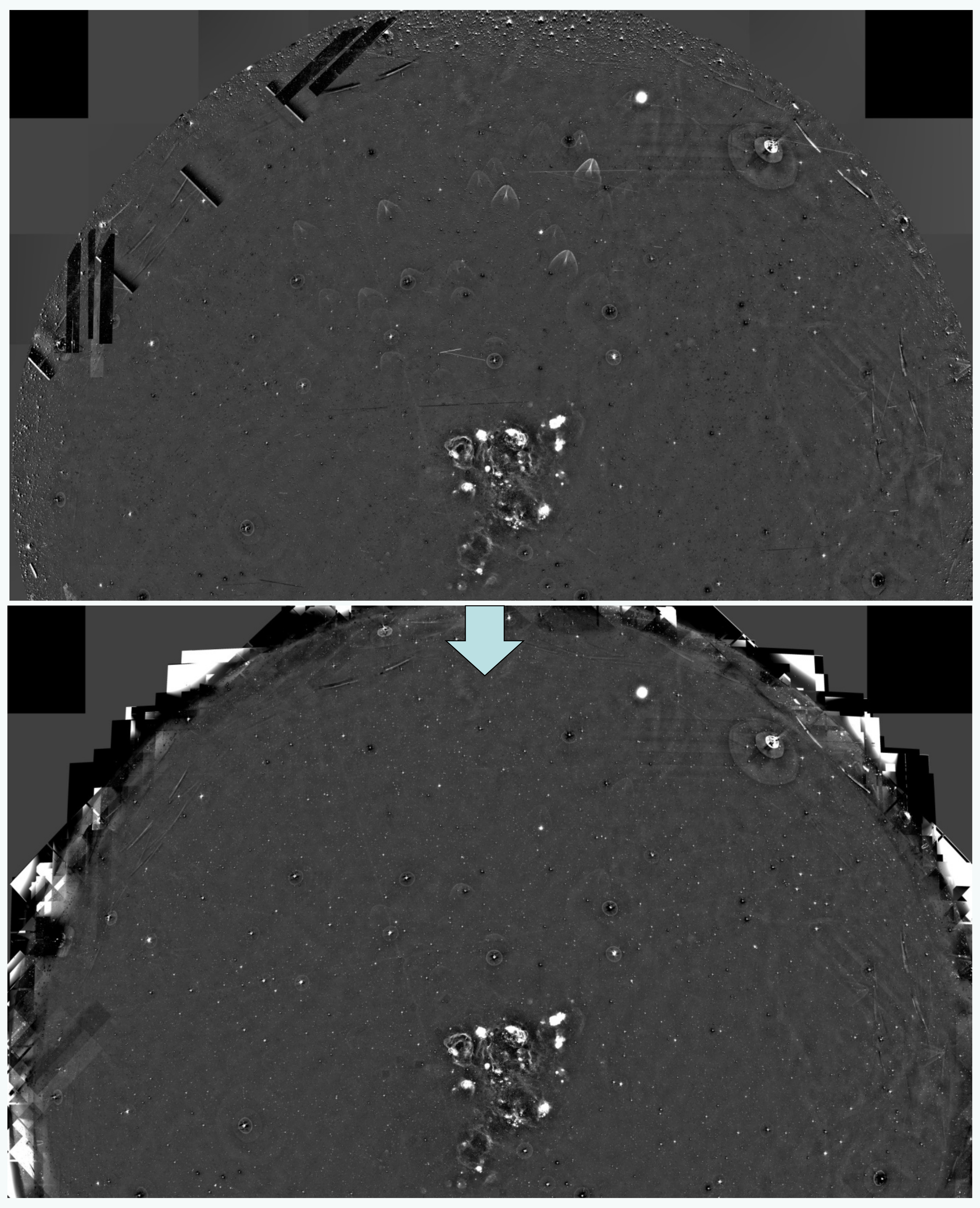

Fig. 4-3: Continuum subtracted Halpha image of NGC 6822 before the ghost removal (top) and after the ghost removal (bottom). After the ghost removal method is applied, the ghosts remained in the continuum subtracted Halpha image are disappeared and the identification of the faint Halpha emission regions becomes very easy and goes deeper.