Integration and test
of the acquisition camera for the Goodman spectrograph

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1 Pictures of the ACAM

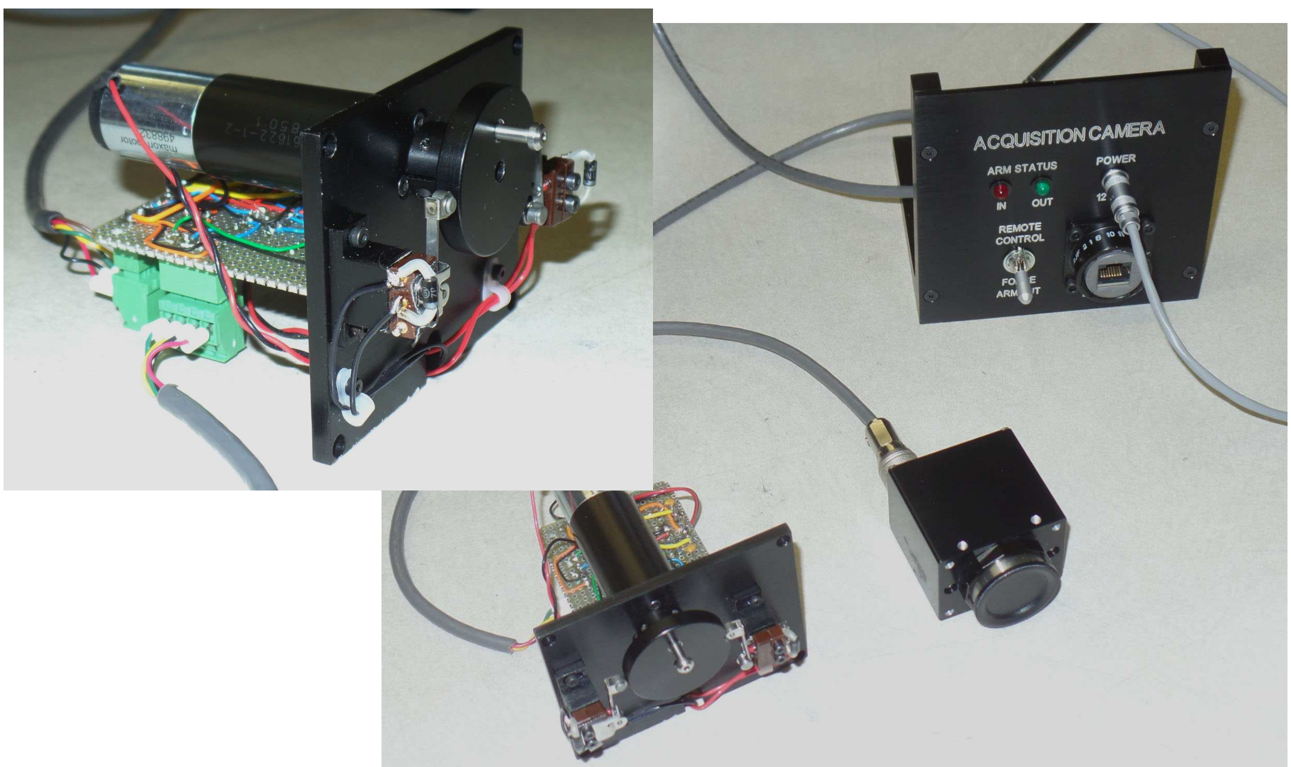

Figure 1: Electronics of ACAM (motor, camera, and connector panel). The insert shows the motor assembly in detail.

The Goodman acquisition camera (hereafter ACAM) was received from mechanical fabrication on May 13, 2015. Its electronics was fabricated a weeek later.

Figure 1 shows the electronics of ACAM. It consists of connector panel and motor assembly. The card with the motor driver and logic is attached behind the motor (in the picture, still provisionally). It has two connectors, one for the connector-panel cable and another for the camera cable. During tests of the motor control, it was found that the inertia prevented the motor from stopping when the limit switches were opened. This is fixed by enlarging the groove in the disk that contacts the switches. The Figure does not show the two auxiliary limit switches used for safety. They are activated when the arm is in the OUT position. One of those switches is used to indicate the arm position by the LEDs on the connector panel.

When the operator moves the switch in the “Arm out” position, the red light indicates that the arm is in the beam, the green light shows that it is out, and the arm moves out independently of its remote control. In normal operation, the switch is in the “Remote control” position, both LEDS are off, and the arm is controlled through the camera. The other safety switch is intended for protecting the Goodman collimator from collision with the arm (either by wiring the colllimator stage motor through this switch, or by reading its state and blocking the collimator motion in the software).

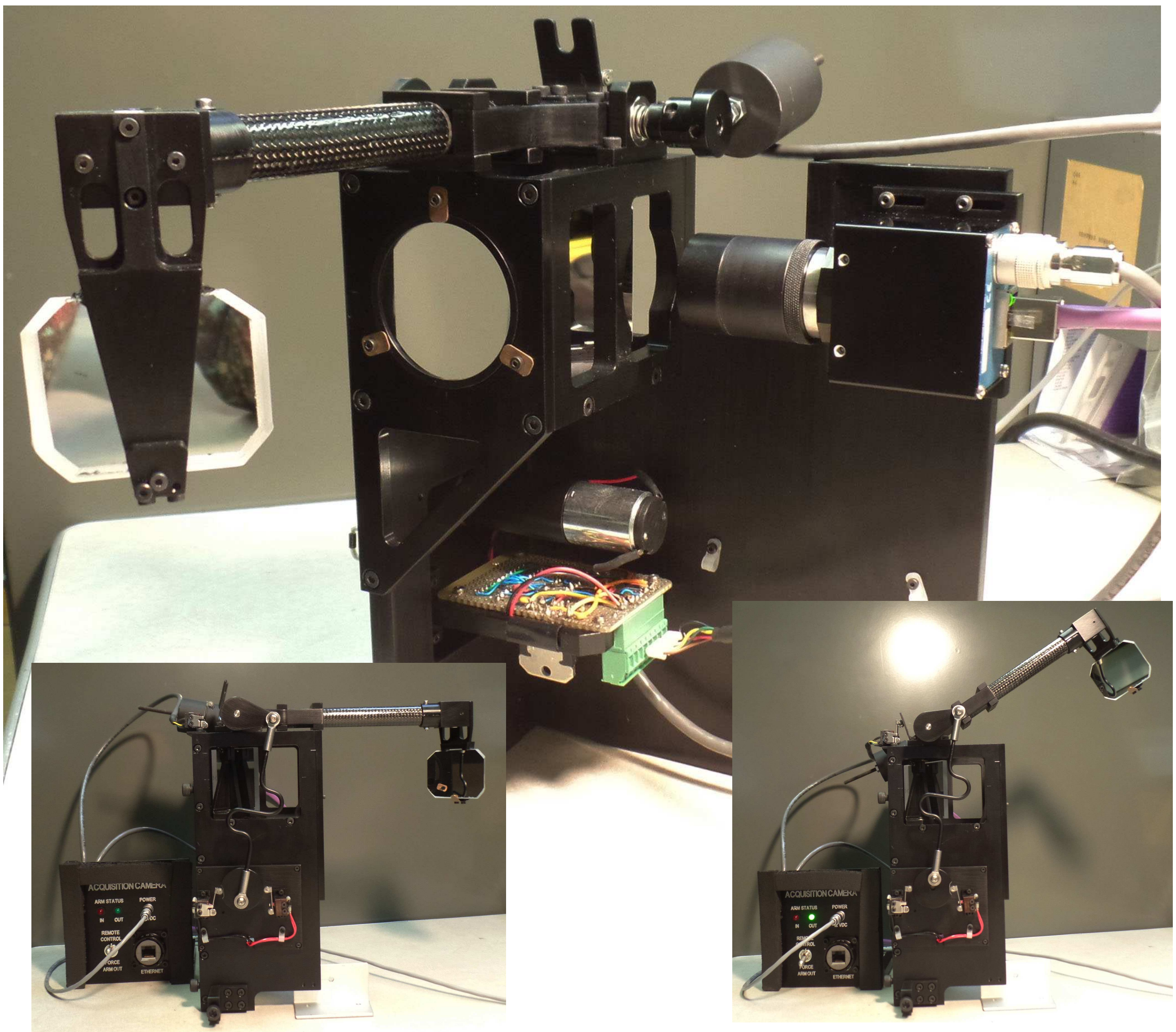

Figure 2: General view of the integrated ACAM. The two inserts show the frontal view with the arm in and out of the beam.

Figure 2 gives the overall view of the assembled device. As it is designed for work inside the spectrograph, there are no covers. ACAM, and especially its arm with the M1 mirror, is quite fragile for handling. Considering this, a wooden handling crate has been made (Fig. 3). Its angular shape imitates the space inside the Goodman spectrograph where the camera will be installed. The device is clamped to the back wall with the screw and plate used to fix it inside the spectrograph. The connector panel is clamped to another wall. The arm is additionally protected from top and side by a removable cover. Without this cover, the device can operate in its crate. We provide a target that can be attached to the crate at the approximate position of the focal plane for focusing and image test before the installation.

For transportation, the counter-weight must be detached. Then the crate with ACAM fits into its cubic box of 30-cm size.

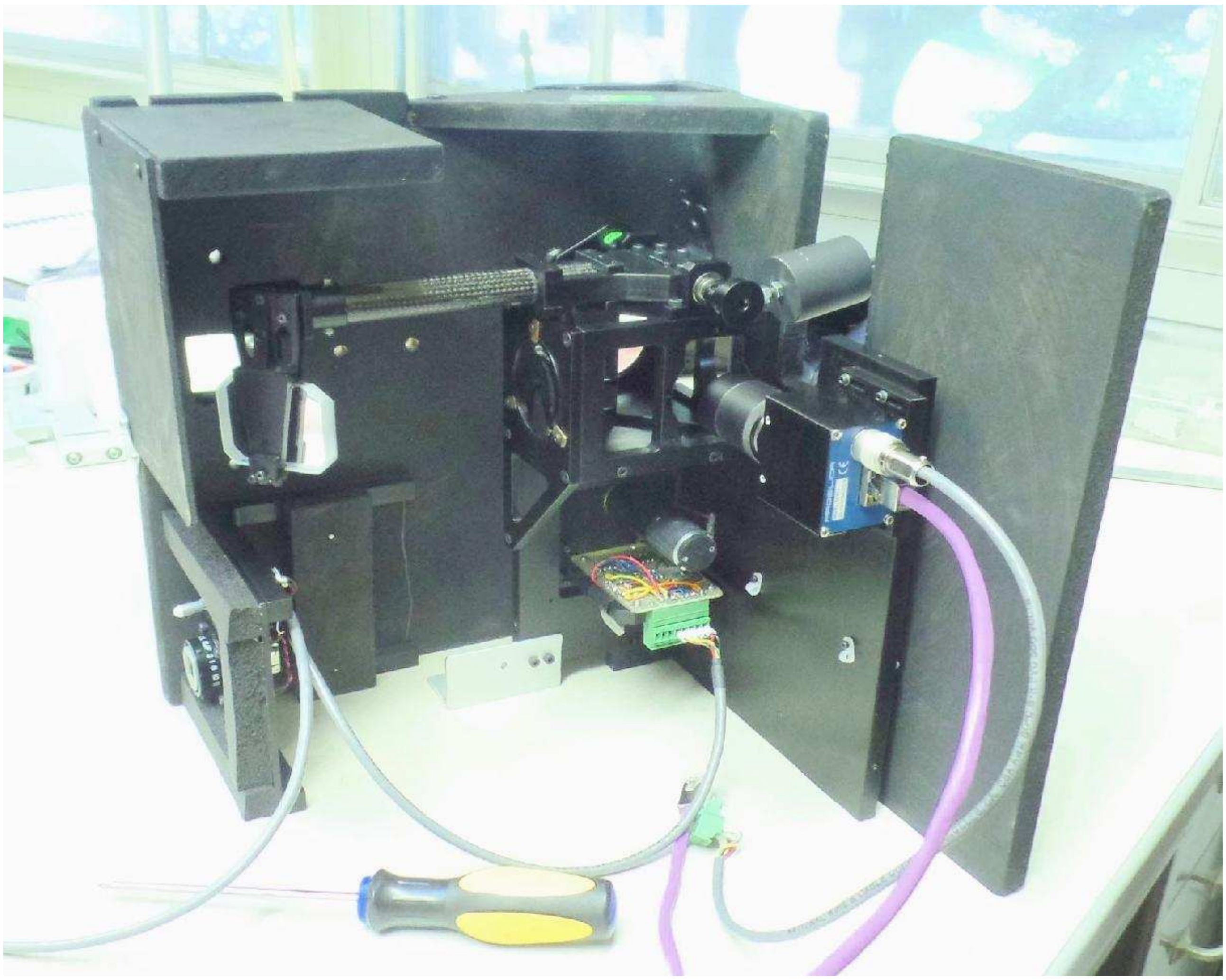

Figure 3: ACAM in its handling crate.

2 Optical alignment

Figure 4 illustrates the alignment process. A provisional "leg" is attached allowing the device to stand on a flat surface (table). The following tools were used:

- Green laser pointer in a mount allowing for tilts and displacement of the beam;
- Optical rail attached to the ACAM body by an auxiliary clamp plate and a screw (easily dismountable);

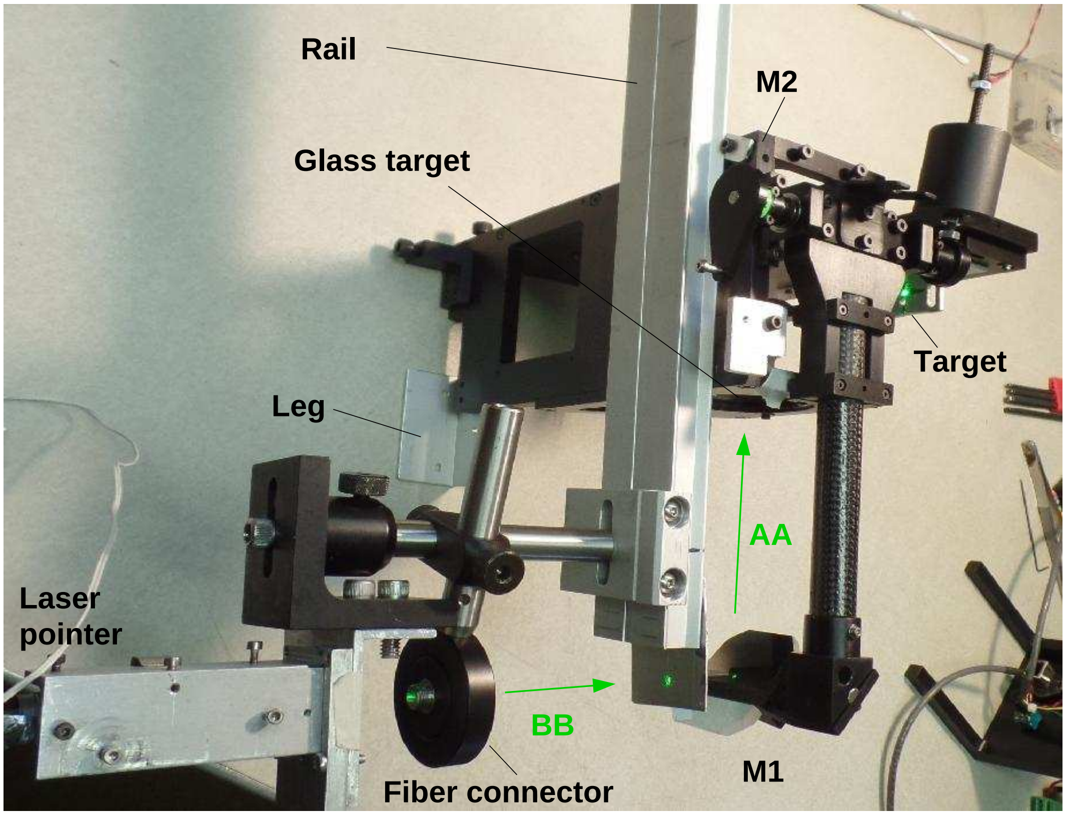

Figure 4: Optical alignment of ACAM mirrors.

- Rectangular flat glass with a cross marking the optical axis, pressed behind the L1 plate (L1 was not installed);
- Target in place of the camera that marks the field center.

Step 1. First, the mirror M1 (at 45° on the arm) was aligned, with M2 removed. The laser beam was directed along optical axis (AA in Fig. 4, but in opposite direction). It was centered on the glass-target cross and reflected back from it to the laser ("auto-collimated" in optical slang). A piece of flat mirror was pressed to the rail, and the angles of M1 were adjusted so that the reflected beam is again directed back.

Step 2. The arm with M1 was temporarily removed, M2 was installed and aligned in angle in the same way as M1. The laser beam was directed along the rail as shown by the AA arrow. A glass pressed to the ACAM wall after reflection from M2 allows to tune the M2 angles for back-reflection to the laser. The lateral position of M2 was adjusted to center the beam on the camera target.

Step 3. The arm was re-installed. Its angle in the horizontal direction is not reproducible after re-installation, so the angle of M1 had to be tweaked. We installed the laser perpendicular to the rail, as shown in Fig. 4, and made its beam BB orthogonal to the rail surface by reflection from a mirror pressed to the rail. The laser was then moved laterally to center the beam on the glass target (after M1 reflection). The reflection from the target returns to the laser after retouching the M1 angular alignment. After the laser was positioned, the fiber connector was placed in the beam to mark the focus position (130 mm in front of the AA axis). The beam reflected from M2 is centered on the camera axis.

Step 4. The three lenses and the camera were mounted to test the image quality and to find the focus. A plastic spacer between L3 and its retaining ring was added to assure firm grip without stress. The lens

L1 is not adjustable. The beam after L1 is almost parallel, so the axial motion of the camera has no effect on the focus.

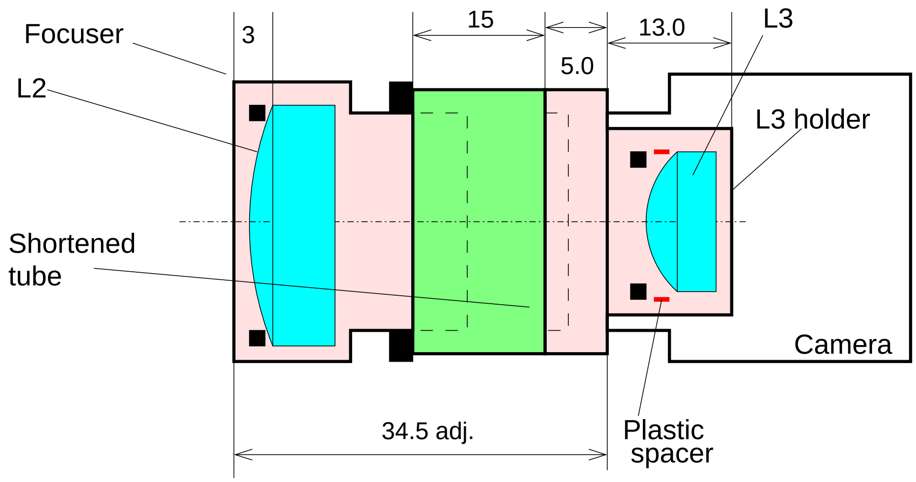

Figure 5: Configuration of lenses L2 and L3. The shortened Thorlabs tube is in light green, the L1 holder and focuser are in pink.

In the original ACAM design, the lens L2 was installed in the 50-mm tube from Thorlabs between two retaining rings, the nominal distance between L2 and L3 being 35 mm. In this configuration, reaching focus was not possible, it remained in front of the CCD. The original plan to use the camera focusing was not tried, as there seemed no room for moving the lens assembly further inside the camera (it is already deep inside). Instead, we focused by approaching L2 to L3. It is not practical to focus by dismounting the L2 from its tube and moving the retaining rings. Instead, we installed the standard focuser from Thorlabs in a tube shortened to 15 mm (Fig. 5). The adjustable length of the assembly (from the front edge of the focuser to the camera flange) is 34.5 mm. The distance between the lenses is then about 21 mm. The focus will be tuned to get sharp image of the slit when ACAM is installed in the spectrograph.

3 Test of the image quality

Images taken during the tests were acquired as fits files, with 8-bit depth. The optics was focused to get the sharpest image on the screen.

The diameter of the 23.5-mm fiber holder image is 423 pixels, hence the camera pixel projects to 0.0555 mm (de-magnification factor 7.5). This corresponds to the pixel scale of $0.17''$ at SOAR and to the field of 111×83 arcseconds. However, the scale will change slightly when the camera will be focused in the spectrograph.

The 100-μm fiber projects to 2 pixels. Images of the fiber illuminated by the green laser were analyzed by selecting the 20×20 pixel fragment around the source, summing the signal along lines and columns and fitting the 1-D profiles by Gaussians. The FWHM of the centered image is 2.5 pixels in both directions ($0.4''$ on the sky), only slightly wider than the fiber. When the source is moved to the edge of the field, some degradation of the image quality becomes apparent. In Fig. 6 (right) the source was located at (X,Y) = (72,303) pixels. It is widened mostly in the vertical direction (full extent $\sim$8 pixels), with a small tail to the left (towards the edge of the field). The Gaussian FWHM in X and Y is 2.8 and 3.6 pixels respectively. The character and magnitude of the off-axis image degradation agree with the optical design (50 μm full spread). Images of a small hole illuminated by white light were also taken and are sharp (the hole diameter

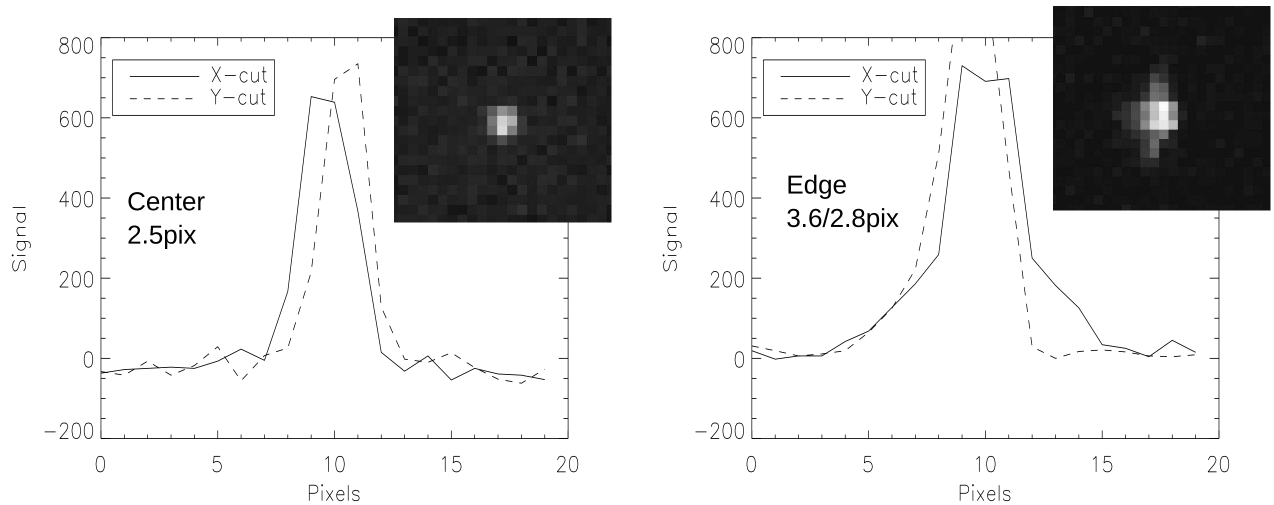

Figure 6: Image quality tests of ACAM. The X,Y labels in the plots are swapped.

was not known to make quantitative analysis). These tests were made with the full aperture, while ACAM will work with the $F/16.5$ beam at SOAR.

4 Removal of AR coating from L2

The lens L2 is designed for work in the infrared and has an anti-reflective (AR) coating that transmits poorly the visible light. This coating has been removed (the vendor, Edmund Optics, refused to sell us an uncoated lens). By experiment, we found that the coating dissolved in the hydrochloric acid (HCL) solution. However, the first experiment dissolved also the surface of the first doublet's component. It is made of the Schott N-LaK22 glass; its optical properties provide for good chromatic correction, and this is why this lens was selected. However, its resistance to acid is poor (class SR 51.2), while the other "flint" component made of the N-SF6 glass is acid-resistant (class 2.0).

On the second lens, we first removed the back-side coating from the flint component. The front-side coating was however affected by the acid vapor, even without its immersion. The coating was then removed by exposing the front surface to the vapor. The lens was mounted in a rubber plate that covered a flask with the acid, with the surface looking down. After several days, the coating was removed while leaving minimal damage to the lens surface. The result is not perfect (increased scattering by point-like defects of the front surface), but good enough for its purpose. The combination of 3 lenses was tested in the optical lab and has shown a good image quality, now confirmed on the assembled device.