Image Processing at ESO

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Most people have some time seen the results of computer treatment of photographs or TV pictures, for instance of satellite photos. It is amazing how an apparently fuzzy, featureless photo of Phobos suddenly reappears with sharp craters and rifts after having been "washed" in a large computer. The past years have seen an enormous increase in the interest in applying the same image-processing techniques to the images of celestial objects, obtained with ground-based telescopes through the Earth's atmosphere. Significant progress has been made in some places, and we here present what has been done at ESO in this direction. The ESO system is described by Frank Middelburg (ESO/Geneva) who wrote the software and developed the features that are now available. Frank has been with ESO for more than nine years, first in Chile on La Silla, but he came back to Europe three years ago. The Image-Processing System is presently used in combination with the ESO S-3000 measuring machine that performs the scans of the photographic plates, but an important feature of this system is that it is directly applicable to any sort of picture: TV as well as photographic, at the telescope as well as afterwards in the laboratory.

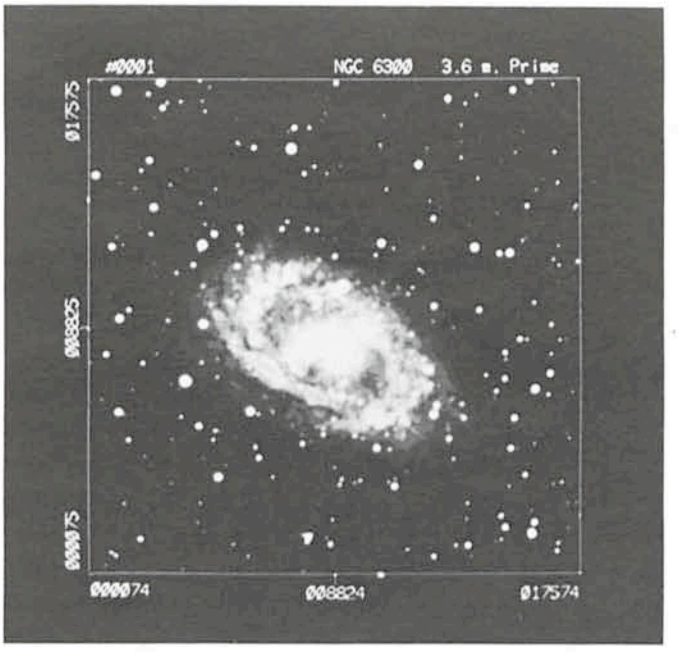

Fig. 1. — *A digitized image. NGC 6300 recorded through photography by S. Laustsen in the prime focus of the 3.6 m telescope. The plate was then digitized by scanning with the Optronics S-3000 microphotometer using a square diaphragm of 100 microns and a sampling step size of 50 microns = .9 arcsec. The brightness scale is plate density which is displayed by 16 levels of quantization. Resolution of the frame is 350 x 350 pixels (picture elements). The frame covers 5.4 arcminutes square. All pictures in this article are digital images which were photographed from the screen of the IMLAC graphic display. Photographic reproduction cannot do justice to the amazing contrast range which the IMLAC is capable of showing.*

When an image is digitized, a sampling process is used to extract from the image values at regularly spaced points. Such a set of samples can be represented for computer-processing purposes as a rectangular array of real numbers. The elements of a digital image or picture are called picture elements or *pixels*.

In astronomy a digitized image may be produced by scanning a *photographic* or an *electronographic* plate with a microphotometer, or the image may be detected and at the same time digitized at the telescope by *television* techniques.

Once an image is digitized, a computer can be used to "improve" the image, such as: better spatial resolution, greater dynamic range or higher signal-to-noise ratio. Then finally the scientific content of the image can be analysed.

As many features in an image can be easily identified by eye yet are difficult to describe algorithmically without ambiguity, an important part of any image-processing computer system is the graphic display device. With such a display and the appropriate software, interactive image processing is feasible. The user seated in front of the graphic display can filter an image, enhance the contrast, etc. while monitoring the results of those manipulations.

The ESO System

In the beginning of 1976, ESO acquired a graphic display device which was duly linked to the in-house computer in Geneva. Soon after that, software development was started. At present an image-processing system is available that will handle many astronomical requirements.

The system consists of an IMLAC graphic display with keyboard, linked to a Hewlett-Packard 21MX host computer with various peripherals attached to it.

The IMLAC has a 21-inch screen of the refreshing type. Besides line drawings, grey scale pictures in sizes of up to 20K pixels can be displayed with 16 levels of quantization. Integral to the IMLAC system is a 24K minicomputer. In our configuration this computer handles the linking with the host computer and does the users I/O via keyboard, cursor or lightpen. However, its main task is the continuous execution of a display programme for generating the picture on the screen. The display programme is dynamically modified by a small resident programme which gets its input via a link from the Hewlett-Packard. This software package, which was designed and written by ESO astronomer S. Lorensen, allows text and graphics to be displayed from the host computer with simple Fortran calls.

The actual processing software executes in a 14K partition of the Hewlett-Packard computer. This machine is not at all dedicated to image processing, the programmes run in a multiprogramming system together with those of other users.

All schemes for further linking to a large out-of-house computer were avoided in order to make an eventual installation in Chile possible.

Images which are selected for processing are read from magnetic tape or disc cartridge to a disc work area. At present this area can hold up to 2 x 10^6 pixels in both inte-

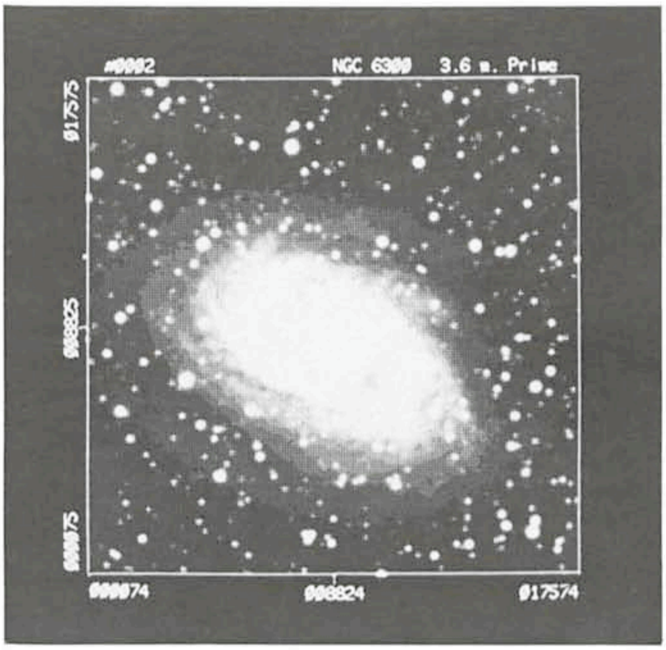

Fig. 2. — *The image of Fig. 1 digitally "squeezed" by a factor of 2, then displayed with a coarser resolution of 175 x 175 pixels. A high threshold was used in an attempt to show the wings of the galaxy (see text).*

ger and floating point format. This on-line storage capability will be doubled in the near future. Completely or partly reduced images may at any time be copied from the work area out again to magnetic tape or disc cartridge. A Calcomp plotter is available for "hard" copies of line drawings as contours and graphs, while for grey scales a polaroid camera can be used.

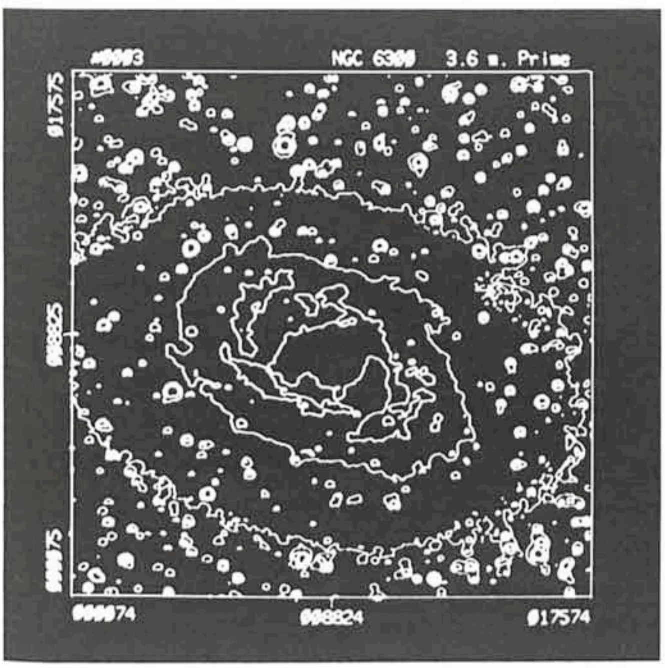

Fig. 3. — *A contour plot with 3 levels. The image shown in Fig. 1 was smoothed with an unweighted window of 3 x 3 pixels. The sample values were also corrected for plate gamma (i.e. the non-linear photographic calibration curve) to achieve a linear brightness scale. Frame size and image resolution are the same as in Fig. 1.*

Software Capabilities

The image processing is controlled interactively by commands with their parameters which are checked for reason and interpreted as they are entered from the keyboard. The command syntax was designed to be understandable by an astronomer or assistant who has a minimal knowledge of computers. Sequences of commands may also be entered into a disc file from where the system can get its control information to run in a batch mode. Commands such as if statements, jumps and loops were developed to allow some programming facilities within batch. Batch is used when the same series of routine commands is often repeated, or to allow the user to do other things while the system processes commands with long execution times. The user can always abort a batch run and take over interactive control.

Up to four images can be shown simultaneously on the screen for comparison. Those images may contain different regions of the same celestial object, the same object observed through different filters or arithmetic operations applied to any of the above. Each image has a fixed size or frame on the screen; however, the user has full control over the scaling and the portion of the image to be displayed within the frame. With scaling an image can be compressed to fit the frame, or a zoom effect can be achieved for a closer look. With large images the frame can be placed on any region desired without loss of resolution as would occur with a compression through scaling.

A cursor can be used to point to features of interest. The system can pick up the position of the cursor and will respond with the exact location and brightness of the feature.

Image Transformations

There are several ways of displaying an image, each having its use. The most straightforward, and usually the most revealing, is a grey scale display. Grey scales are very suitable for showing the results of linear and non-linear contrast manipulations. As the information contents of an image is often larger than the mind can register in a single glance, the computer can enhance an image to show only some of the information that it contains. Contrast can be improved by stretching out the digitized levels of an interesting part of the data to cover the quantization range. The regions falling outside the range are then simply ignored. This technique, which has the advantage that the image remains linear, is useful to determine how far the wings of a galaxy extend into the sky background. Other methods of showing an image are by contours (Fig. 3), multiple line scans (Fig. 4) and bilevel pictures. Multiple scans with "hidden" lines are suitable for images with sharp brightness transitions as stars, they give less information when the shading varies slowly. Bilevel pictures consist of only two grey levels, the separation given by a single threshold. As they are very efficient in display computer memory, they can have a big frame. A large amount of qualitative information on an image can be obtained with a "histogram", which is a plot of the number of times each grey level occurred in the image as a function of the grey level. Displaying a histogram is usually the first step in processing a new image as it is a quick way to estimate exposure and contrast.

Noise Removal

Often an image must have its noise removed by smoothing or filtering. The basic difficulty with noise removal techniques is that, if applied indiscriminately, they tend to blur

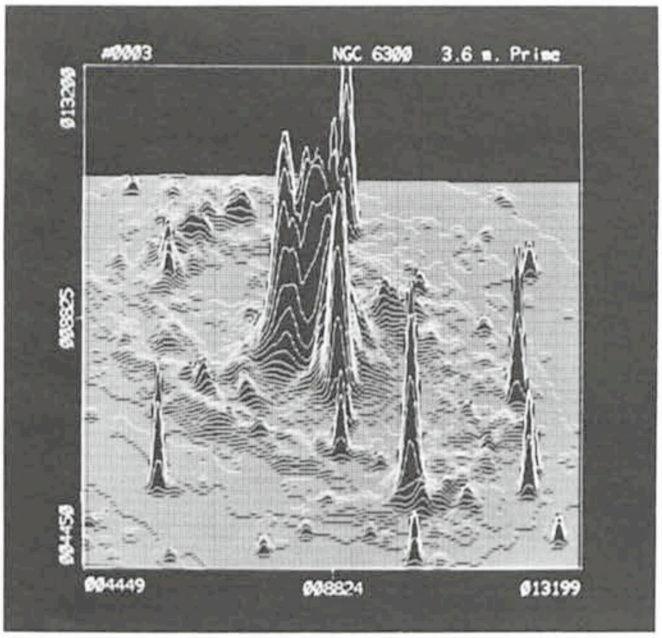

Fig. 4. — *Multiple line scan. The central region of Fig. 3 scaled up by 2. Here also the brightness scale is linear.*

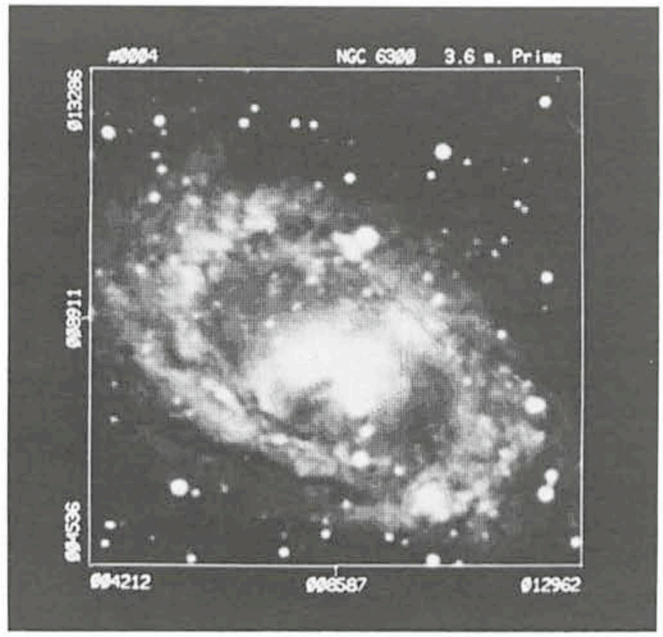

Fig. 5. — *Central region of the same plate now scanned with a diaphragm of 60 microns and a step of 30 microns = .6 arcsecond. The image was digitally squeezed by a factor of 2 and then displayed with 175 x 175 pixels. The reason for this squeezing is that it is not always possible to hold a picture with the highest resolution in the display processors memory. Brightness is plate density.*

the image. The system offers several methods to achieve a "smoother" image. For example, where a data point is represented by more than one pixel, weighted window averaging could be used. A square window of specified size is placed around each pixel, and a weighted average intensity of all pixels in the window is used as the new value of the central pixel. Gaussian weighting factors are normally used. The resulting image allows the eye to see a more continuous distribution of intensities.

At a certain stage a quantitative restauration may have to be made of the image to convert it from an instrumental system to an astronomical meaningful system of photons per pixel. All imaging systems as photography and TV devices degrade the image in some manner or other. For photographic plates routines were developed for the non-linear transformation of densities to intensities. TV-type sensors show the problem of non-uniform photometric response. However, if an image that is made by the same sensor of a uniform field (called an exposure mapping) is available, then the restauration is straightforward. Each pixel of the original data is divided by the corresponding pixel of the mapping, which achieves the effect of a uniform image.

Image Arithmetics

A powerful facility of the system is the capacity to perform calculations based on images. These calculations can include various arithmetic operations as adding, subtracting, multiplying or dividing. In fact, a command is available that can do many calculations on several images in a single pass. Thus images can be combined to construct other images with astronomical meaning. For example, after alignment, the difference of two images could be used to map the B-V colour structure of galaxies.

Other routines available in the ESO image-processing system worth mentioning are: removal of unwanted details in an image by polynomial interpolation over the surrounding area, image rotation and shifting, area integration for determining the flux of stars or extended object, and many utility routines as listing, dumping, logging and directory listings.

All the images described above were tacitly assumed to be two-dimensional. However, single-dimensional images as produced by scans of spectra can very well also be handled by this system. Most of the routines, e.g. filtering and non-linear calibration, work with both single and two-dimensional data. Various modules were added to handle spectral data only as transformations to a linear wavelength scale, line area integration and interactive continuum determination.

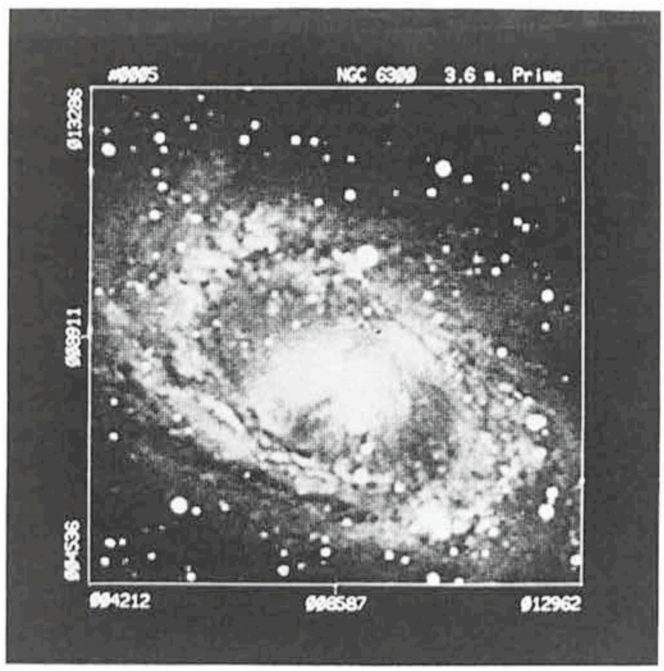

Fig. 6.—*A laplacian sharpening filter applied to the image of Fig. 5. The high spatial frequencies were boosted leaving the low ones relatively unaffected. Note the increase in fine detail.*

Real-time Reduction

As the I/O with the graphic display is routed through a single module, the system can be easily modified to work with other than an IMLAC display. In fact, it is planned to use parts of the image-processing system at the telescope with a Tektronix display for the real-time reduction of data produced by an image dissector scanner.

In its present state the system consists of 97 commands with varying levels of computer sophistication. However, further development has not stopped. New routines are being regularly added with the aim of providing more reduction facilities in those areas of astronomy where imagery is the basic data format.

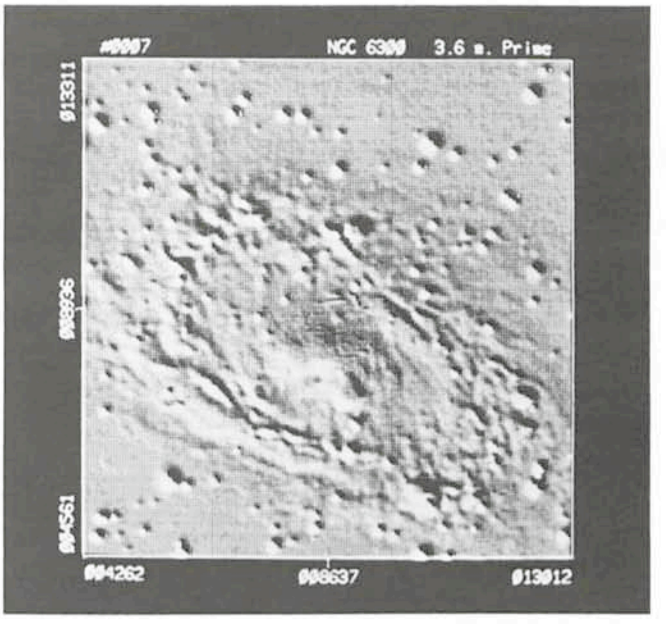

Fig. 7. — *Subtracting a slightly misaligned image from itself produces this. The lower and the higher grey levels show where the slope is the steepest.* ▶

The Large-Field Camera for the 3.6 m Telescope

One of the important features of the ESO 3.6 m telescope is that the optics permit a comparatively large field (about 1°) to be imaged on a photographic plate in the prime focus. This is possible due to the chosen shape of the primary mirror (modified Ritchey-Chrétien) and a triplet corrector in front of the photographic plate. The large-field camera is now ready for shipment to La Silla. It incorporates some unusual features that are not seen at other telescopes and was designed by ESO engineer Sten Milner in Geneva. He gives this information to the future users:

The large-field camera (Fig. 1) was received from the manufacturer in July 1977 and is now undergoing thorough testing at ESO, Geneva, before being shipped to La Silla, at the end of the year. It can be mounted in the Cassegrain focus, but will mainly be used in prime focus as soon as this focus gets equipped with the triplet adapter in mid-1978.

The camera consists of a manually *"quick-connect"* plate holder, a remotely-controlled shutter and a filter box with four filters, either colour or interference filters. The fil-

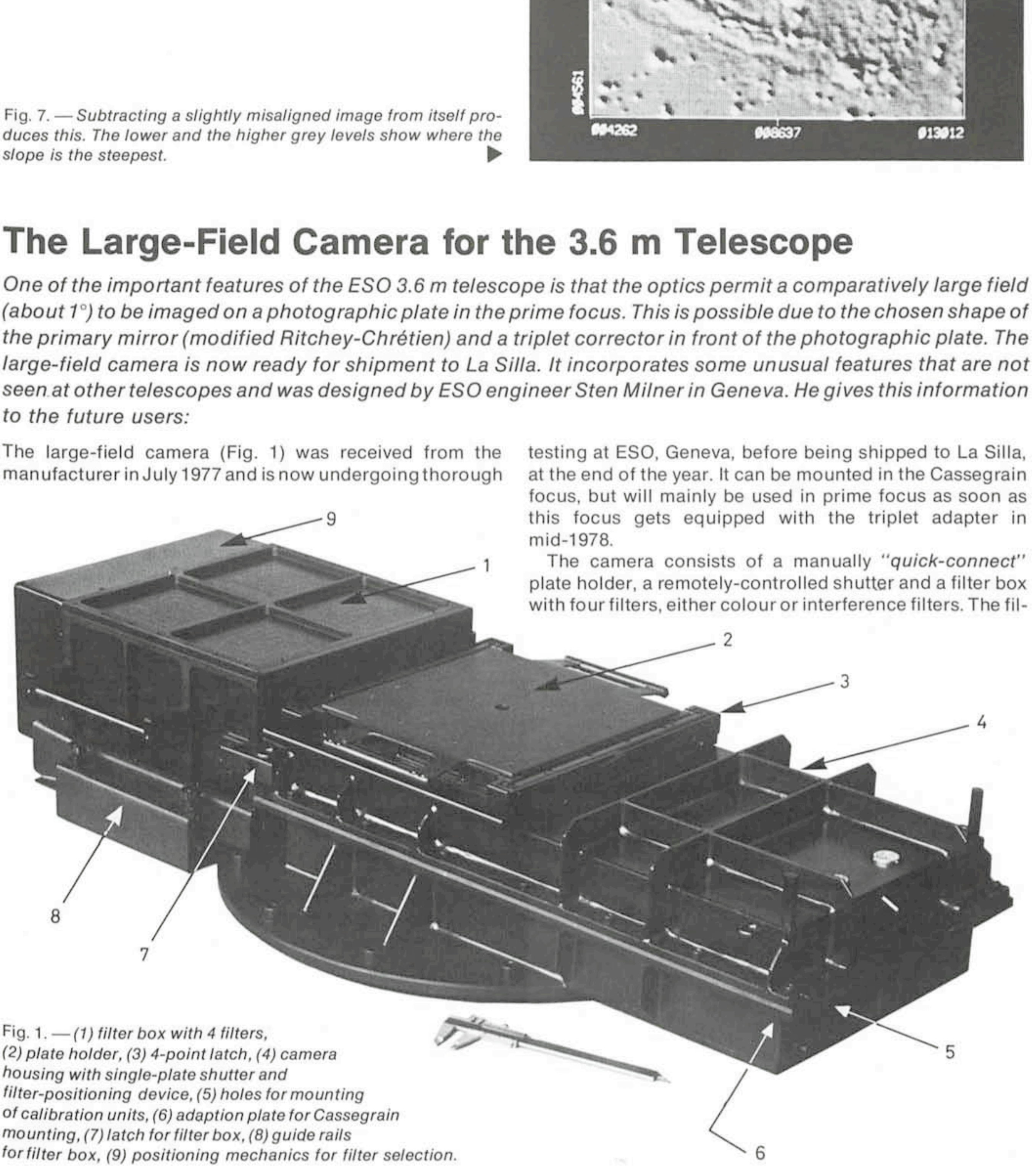

Fig. 1. — *(1) filter box with 4 filters, (2) plate holder, (3) 4-point latch, (4) camera housing with single-plate shutter and filter-positioning device, (5) holes for mounting of calibration units, (6) adaption plate for Cassegrain mounting, (7) latch for filter box, (8) guide rails for filter box, (9) positioning mechanics for filter selection.*