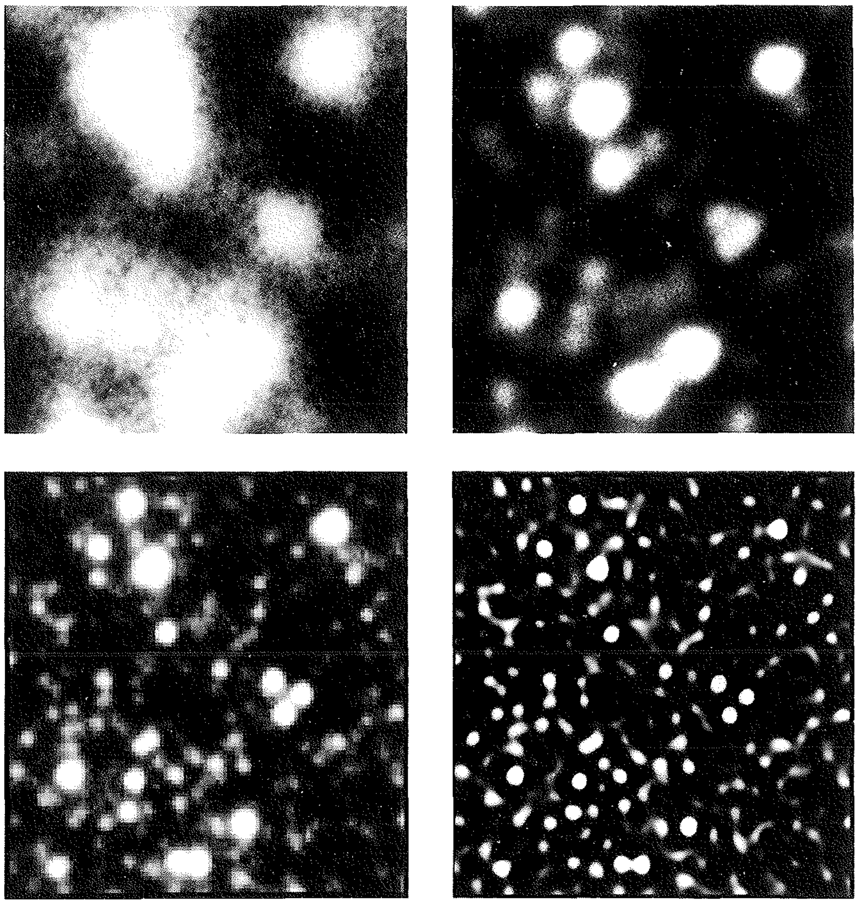
A Revolution in Ground-based Direct-imaging Resolution



These four images illustrate the importance of improving the resolution of astronomical images. They demonstrate the great potential of the ESO New Technology Telescope (NTT), in terms of finer details and fainter limiting magnitude, as compared to other telescopes.

The field shown is near the centre of the bright southern globular cluster ω Centauri. It measures 12 × 12 arcseconds and covers about 1/16 of the area of a CCD frame, obtained with the NTT on the night of "First Light", see the picture on page 1.

The first (upper left) picture is an enlargement of a photographic plate obtained in 1984 with the ESO Schmidt telescope under seeing conditions mediocre by La Silla standards (~ 2 arcsec). The exposure time was 10 min on unsensitized, blue-sensitive IIIa-J emulsion behind a GG 495 filter (spectral range 500 – 540 nm). The original image scale is 67.5 arcsec/mm; i.e. the field shown corresponds to 0.18 × 0.18 mm on the original 30 × 30 cm plate. In other words, about 2.6 million fields of this size are contained on the Schmidt plate.

Next (upper right) follows an excellent photographic plate obtained at the Cassegrain focus of the ESO 3.6 m telescope in 1977. The exposure lasted 6 min 15 sec and the seeing was ~ 1 arcsecond. The emulsion was IIIa-J and no filter was used (spectral range 300–540 nm). The image scale is 7.2 arcsec/mm; on the original 6 × 6 cm plate this field measures 1.7 × 1.7 mm.

A 10 sec unfiltered CCD exposure was made with the NTT at the moment of "First Light" on March 23, 1989; a small part of it is shown here in two versions. The first (lower left) is the "raw" 100 × 100 pixel image (pixel size 0.123 arcseconds). The Full Width at Half Maximum (FWHM), as measured directly on the stellar images in the frame is 0.33 arcseconds. To this value, the NTT optics contributed perhaps 0.15 arcseconds, so that the actual, atmospherically induced seeing may have been better than 0.3 arcseconds, a spectacular value, even by La Silla standards.

At the lower right, the same frame is shown after "sharpening" by advanced image processing. For this, the frame was subjected to deconvolution with a point spread function, which was empirically constructed from 50 profiles of uncontaminated stellar images and at the same time resampled at 1/5 of the pixel size in both directions. The FWHM is now improved to 0.18 arcseconds; the stellar images are noticeably sharper and faint stars are much better visible. To facilitate the comparison, the intensity scale is the same in both NTT frames.

The image processing was made by Dietrich Baade at the ESO MIDAS facility in Garching with an algorithm developed by Leon Lucy. About 3 hours VAX 8600 CPU time was needed to perform 20 iterations; this time can of course be significantly reduced with other computers, optimized for "number-crunching".

The improvement in resolution is dramatic, as illustrated for instance by the triple star, just right of the field centre. The distance between the two components which are closest to each other, is only 0.79 arcseconds. The Schmidt picture does not indicate any multiplicity, the 3.6 m barely resolves the system, while the NTT shows the three components, well detached from each other. Note also the resolution of the double system near the lower border, here the distance is 0.59 arcseconds.

Since the light is better concentrated on the detector, the higher resolution also leads to fainter limiting magnitudes. The 10 second NTT exposure reaches about magnitude 20. A simple extrapolation then predicts that a limiting magnitude well beyond 27 mag may be reached with the NTT within a reasonable exposure time. The actually achievable value will of course also depend on other factors, like the sky background and the accuracy of the tracking.

correction. The *passive* correction of coma had been so accurate that the final *active* correction established only required x, y movements of 0.176 mm and 0.031 mm respectively, only tiny fractions of the nominal range available of ± 5 mm. Although the relatively large value of spherical aberration originally found has been actively fully corrected and therefore does not finally worry us, it is still important to understand its origin. This will be investigated further.

The CCD of the image analyser was dismounted and set up via a 45° mirror directly in the telescope focus. On the evening of 22 March we were ready for "First Light" in the true sense of the first astronomical images with the optimized optical system. The field available with direct imaging on the CCD was only *47 arcsec*, so account had to be taken of this in selecting objects. A further important parameter was the exposure time. A true judgement of the quality of the telescope image always requires an exposure time which integrates out the external seeing. With very good seeing,