Photometric Techniques II
Data analysis, errors, completeness

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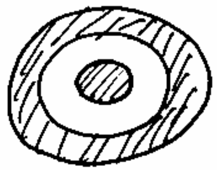
CCD RELATIVE (INSTRUMENTAL) PHOTOMETRY

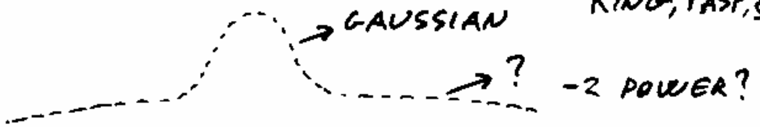
APERTURE PHOTOMETRY:



PROBLEMS: 1) CROWDING
2) SIZE OF THE APERTURE:
- S/N RATIO OR (BIG APERTU[R]
- CENTERING PROBLEMS (SMALL "

FITTING TECHNIQUES:

WHAT IS THE SHAPE OF STELLAR IMAGES?
THE PSF (POINT SPREAD FUNCTION) PROBLEM
-GAUSSIAN ONLY IN THE CENRAL PART
-EXTENDED WIDE WINGS IN THE OUTER PAR[T]
KING, PASP, 83, 199



1) GAUSSIAN + EMPIRICAL (STETSON 1987)
2) MOFFAT (MOFFAT, A.A. 3, 455, 1969
3) LORENTZIAN (DIEGO, PASP, 97, 1209, 1985)
SEE ALSO BUONANNO (A.A., 126, 278, 1983)

The fitting technique assumes the linearity of the intensity values and a constant PSF shape with the intensity level

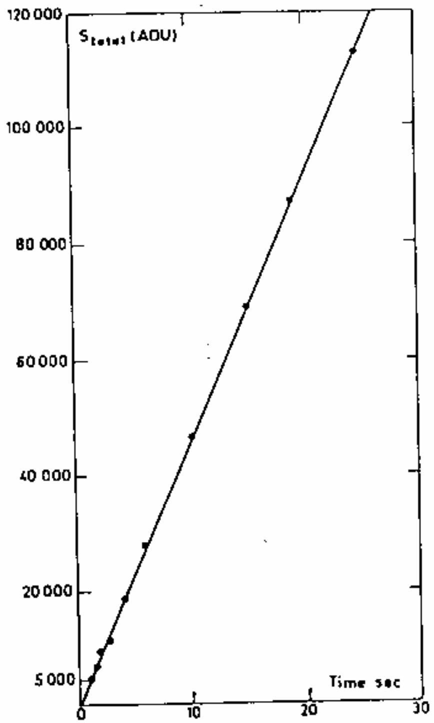


Fig. 3a. Linearity of the CCD. The straight line is the total output signal on the central pixel and those on the same column.

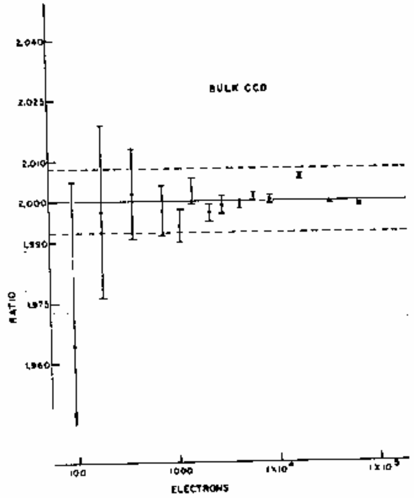


Figure 11. Linearity plot of an RCA bulk CCD.

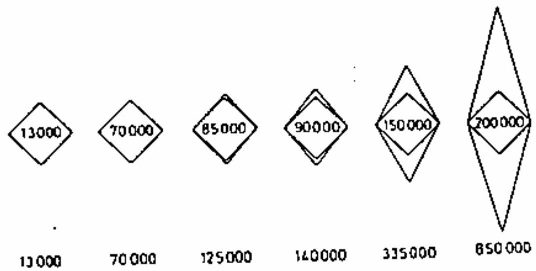


Fig. 3b. Evolution of the FWHM with input signal increase: the output signal on the illuminated pixel is represented on the central diamond. We mention below each of them the total charge read by the CCD. Note the diamond shape along the columns whereas no degradation is observed along the rows

There is also recent evidence of "non linearity" of the poissonian noise in the flat fields (Downing et al., SPIE 2006)

In conclusion the intensity level of the CCD is linear up to the saturation limit, but there is a spilling of charges well before the saturation

A practical suggestion:

1) **Stars with a peak above 90% of the saturation value should be not used for calibration neither for the PSF.**

The best choice is a star with the peak at half of the dynamic range

Before starting…..

There are at least four parameters you should know before starting:

1. Read out noise;
2. Conversion factor (electrons to ADU);
3. Maximum linear signal (physical or electronic saturation level);
4. Size of typical stellar images (seeing, FWHM in pixels)

Fundamental tasks for stellar photometry

FIND — crude estimate of star postion and brightness + + preliminary ap. photom.

PSF — determine stellar profile (point spread function)

FIT — fit the PSF to multiple, overlapping stellar images (and sky)

Further analysis of the data:

SUBTRACT — subtract stellar images from the frame

ADD — add artificial stellar images to the frame

FIND

Basic idea: A star is brighter than its sorrounding;

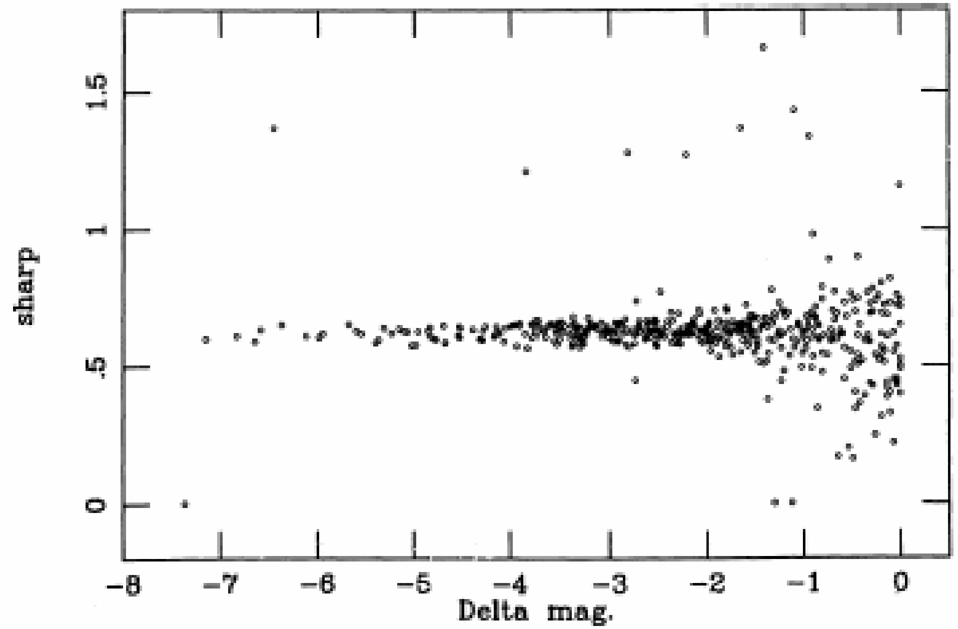
Simple method: set a brightness threshold at some level above the sky brightness level;

Complications:

1. The sky brightness might vary across the frame

2. Blended objects, extended objects, artifacts, cosmic rays must be recognized. Some filtering should be applied.

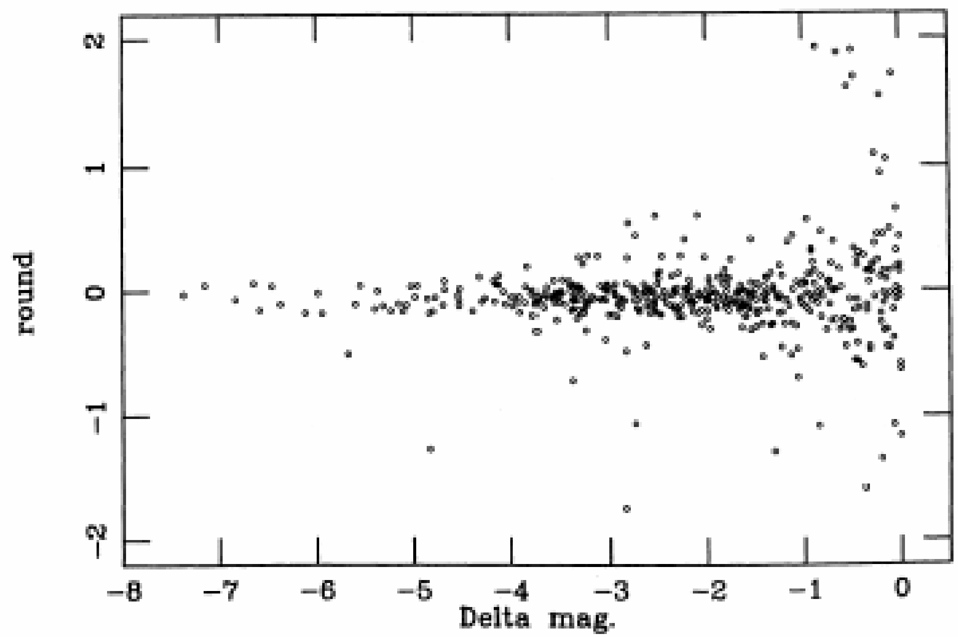
Two parameters to help eliminating non-stellar objects:



SHARPNESS

$d_{i0,j0} = D_{i0,j0} / \langle D_{i,j} \rangle$, with (i,j) near ($i_0$,$j_0$), but different from ($i_0$,$j_0$)

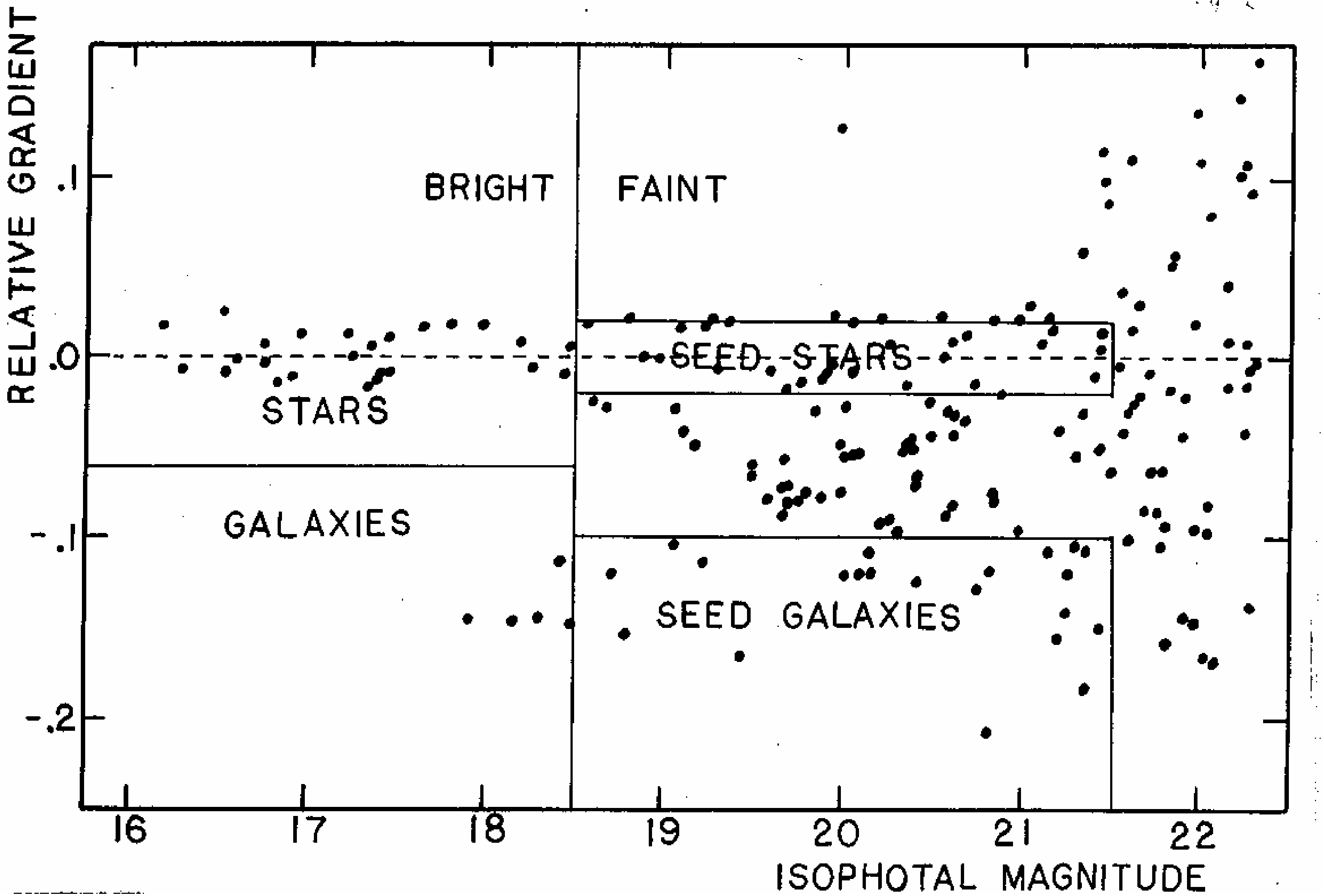
$SHARP = d_{i0,j0}/C_{i0,j0}$



ROUNDNESS

$ROUND = 2*(C_x - C_y)/(C_x + C_y)$

C_x from the monodimensional Gaussian fit along the x direction
C_y from the monodimensional Gaussian fit along the y direction


RELATIVE GRADIENT
.1
.0
-.1
-.2
BRIGHT
FAINT
STARS
GALAXIES
SEED STARS
SEED GALAXIES
16
17
18
19
20
21
22
ISOPHOTAL MAGNITUDE

WEST, KRUSZEWSKI

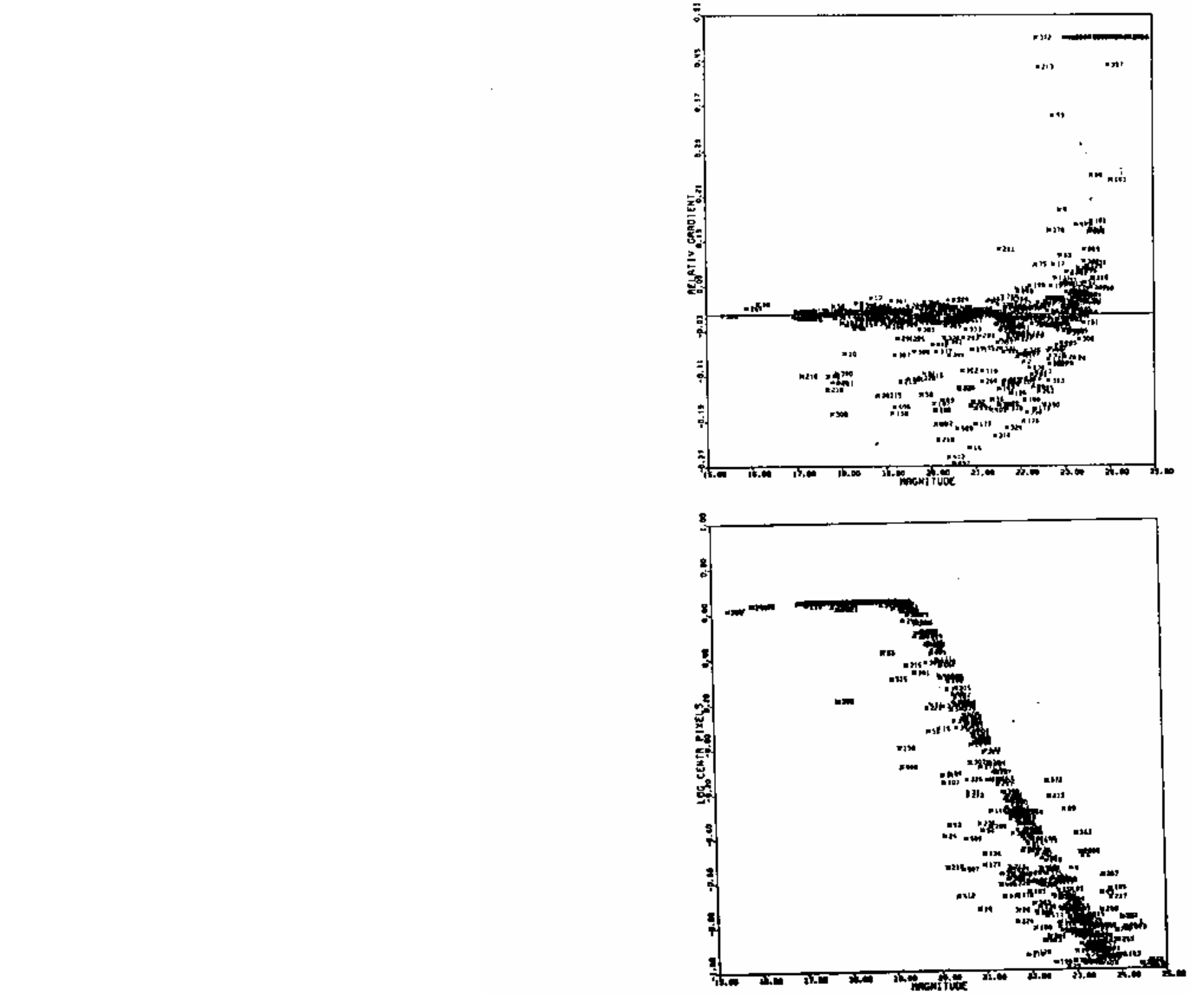
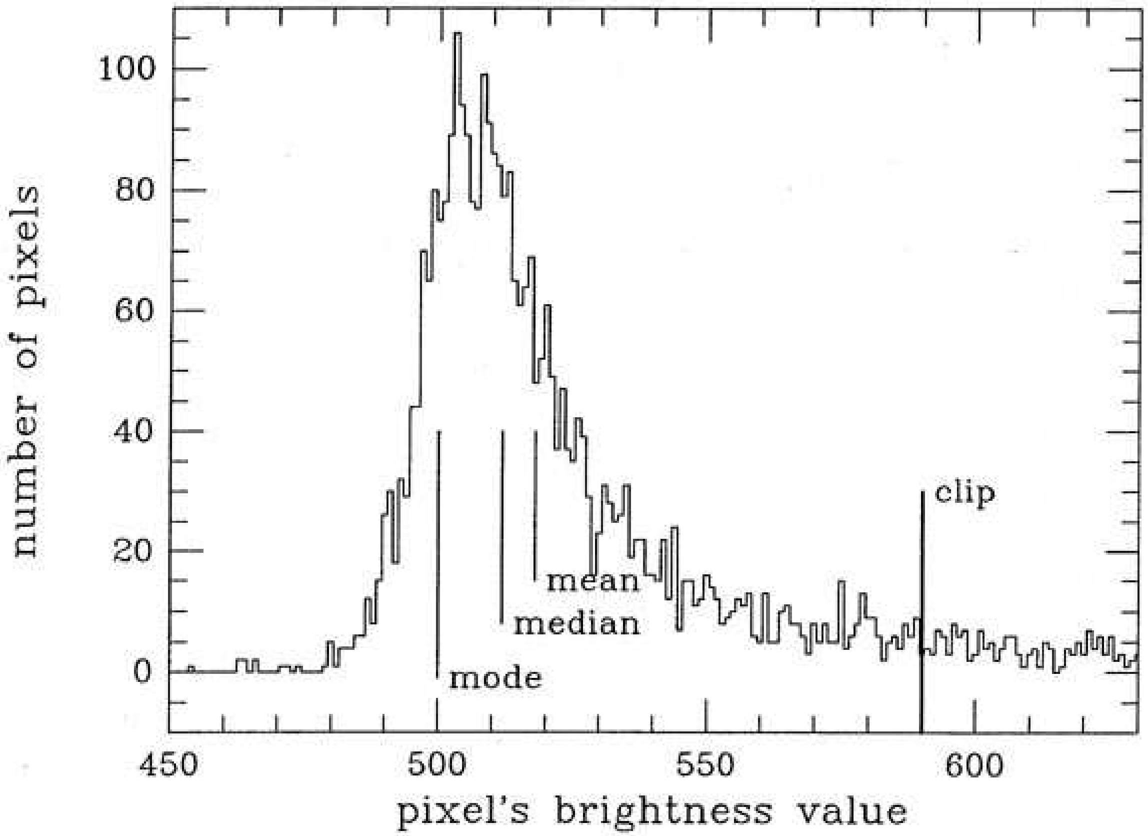


Figure 4. An example of plots of classification parameters in the field of cluster 1922-758, cf. Figure 3. The parameters shown here are: isophotal magnitude, relative gradient, and central surface brightness. The zero-point for the magnitude scale was set arbitrarily (but conservatively) by adopting a sky surface brightness level of 22.5 mag/arcsec^2. No corrections were made to remove the effect of saturation. The limiting isophote corresponds to 26.5 mag/arcsec^2. The relative gradient is calculated by a straight-line least-squares fit to the logarithmic deviation of the image profile from an average stellar image profile. The central surface brightness is calculated as an average of the intensity of the 9 central pixels in the image in units of sky background. It is here plotted on a logarithmic scale. The stars form narrow sequences in both diagrams. Galaxies lie below and to the left with respect to the stellar sequences. Plate defects fall above and to the right (e.g. [illegible] the one-pixel defects in the upper right corner of the first plot and the line formed by

Background evaluation

The background measurement can be rather tricky (because of the crowding)

A good estimate of the local sky brightness is the mode of the distribution of the pixel counts in an annular aperture around the stars. Poisson errors make the peak of the histogram rather messy.



A good guess of the background level is:

mode=3x(median)-2x(mean)

(which is striclty true for a gaussian distribution)

The background can be also derived from fitting.

The stellar profile model: the PSF

The detailed shape of the average stellar profile in a digital frame must be encoded and stored in a format the computer can read and use for the subsequent fitting operations.

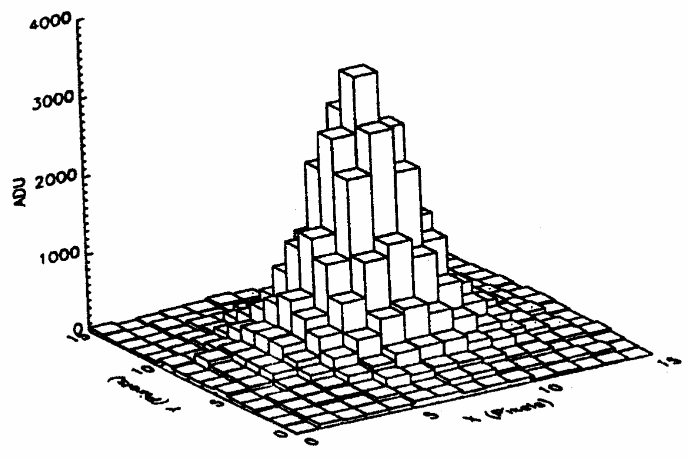
There are three possible approaches:

1. The analytic PSF. E.g. a gaussian, or, better a Moffat function:

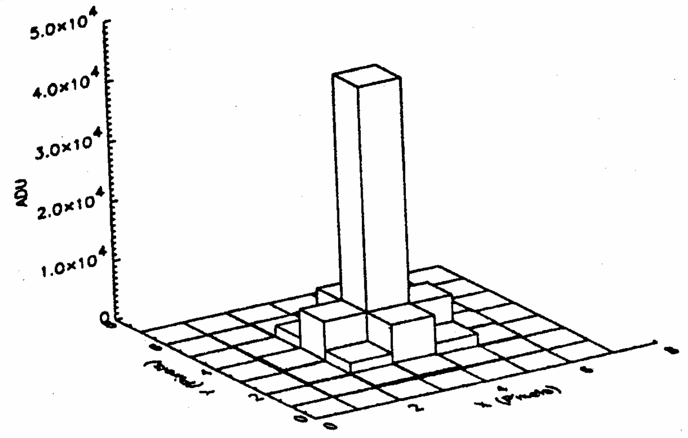
$$S(r;C,B,R,\beta) = \frac{C}{\left(1+\frac{r^2}{R^2}\right)^{\beta}} + B,$$

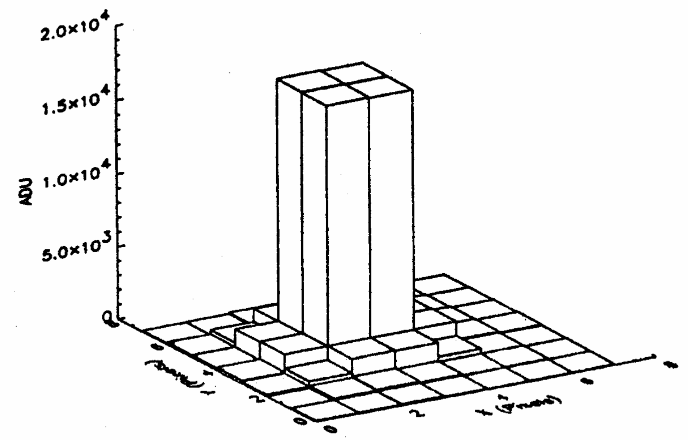
2. The empirical PSF. i.e. a matrix of numbers representing the stellar profile.

3. The hybrid PSF. i.e. a function in the core and a matrix of numbers in the outer regions.



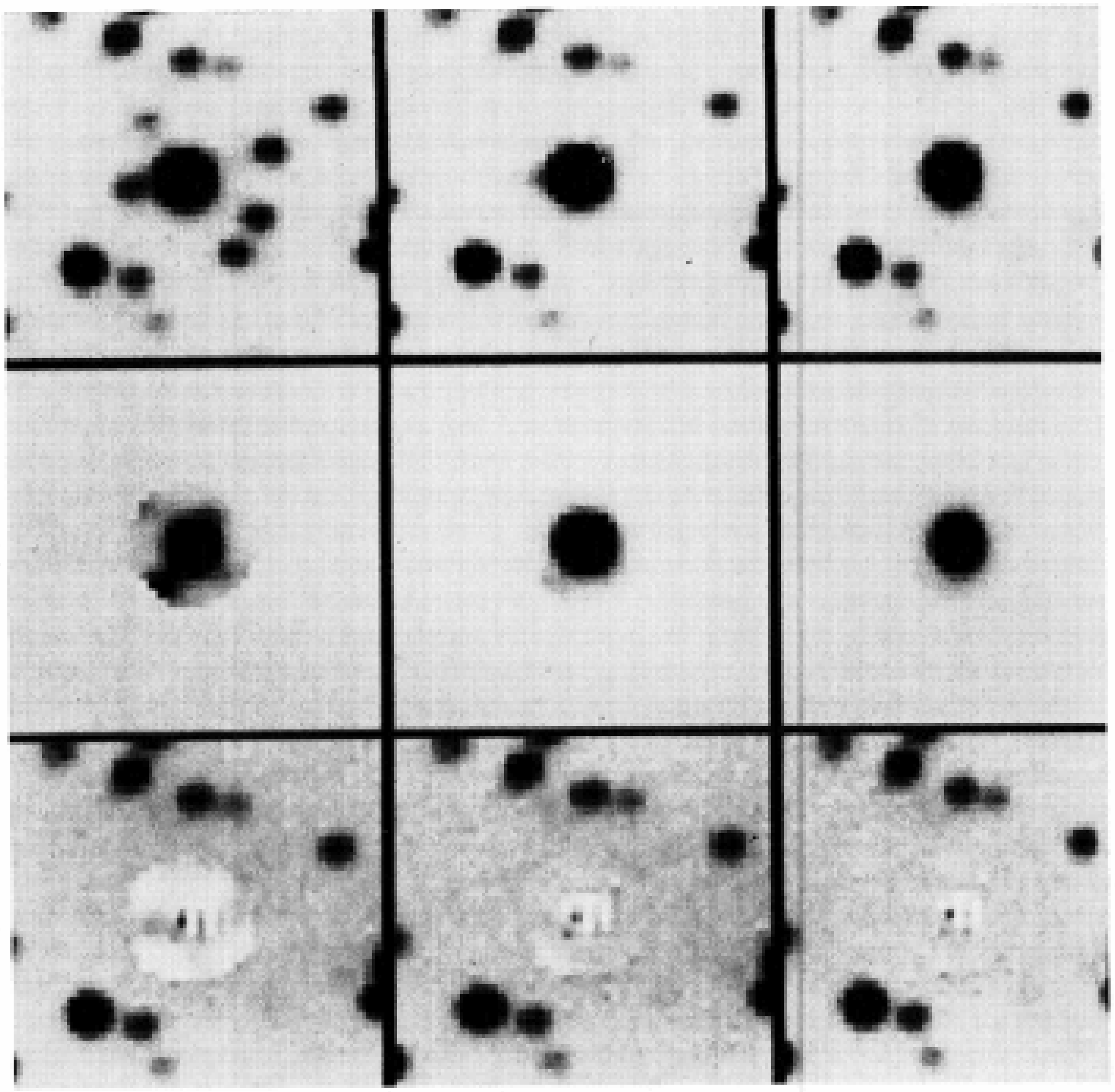
Well sampled stars: ideal case
Limit around FWHM 2-3 pix.





Badly undersampled. Star profile strongly depends on the position of the center within the central pixel. The problem is worsened by the intra-pixel sensibility variation.

The PSF determination is an iterative process!



The PSF model after three iterations

After the starting guesses of the centroids (FIND) and brightness (PHOTOMETRY) are measured, and the PSF model determined (PSF), **the PSF is first shifted and scaled to the position and brightness of each star**, and each profile is subtracted, out to the profile radius, from the original image. This results in an array of residuals containing the sky brightness, random noise, **residual stars** and systematic errors due to inaccuracies in the estimate of the stellar parameters.

You may proceed further with a second search and analysis.

THE PHOTOMETRIC ERRORS

Once we have the final photometry we have to determine the photometric errors for the single stars. This is not an obvious task because many error sources contributes to the final uncertainty of the data. Four different methods can be used:

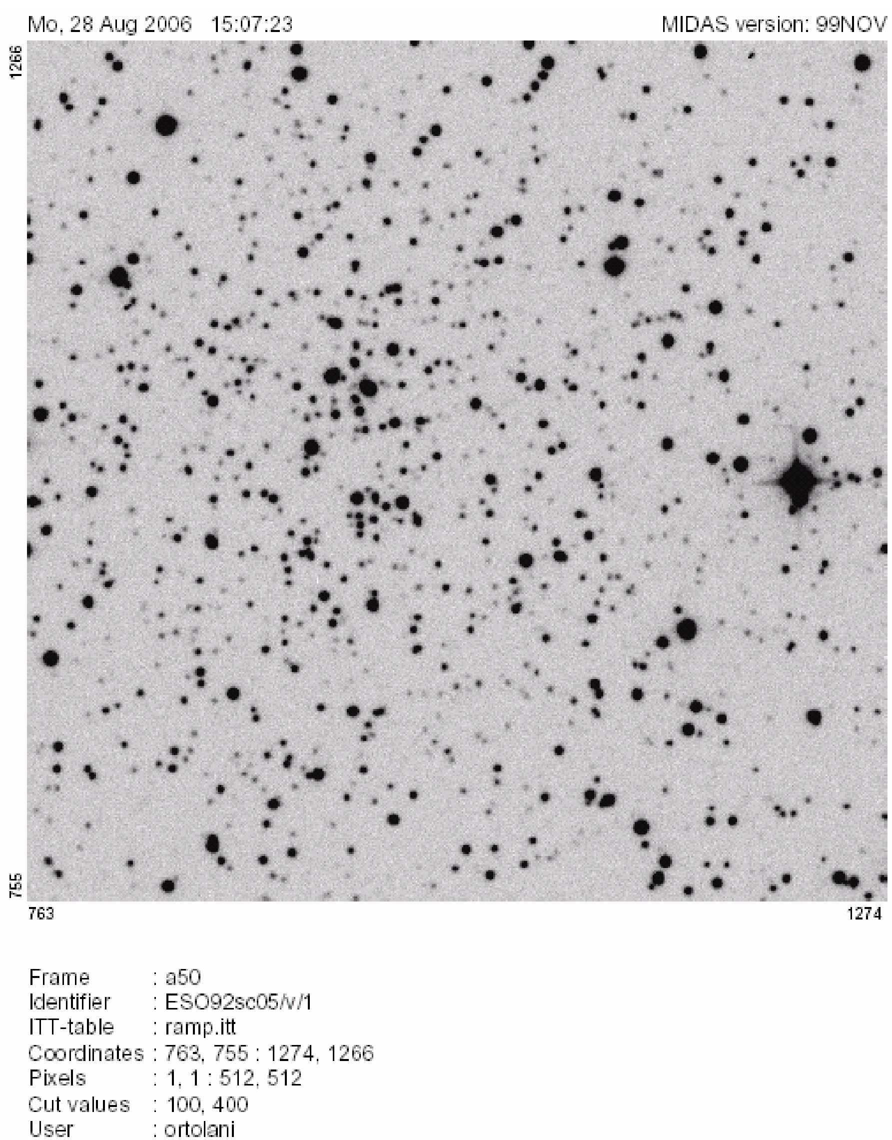
1) DAOPHOT gives the statistical error for each star (lower limit !).

2) Another obvious method is to compare the measurements from couples of images (still lower than the real one).

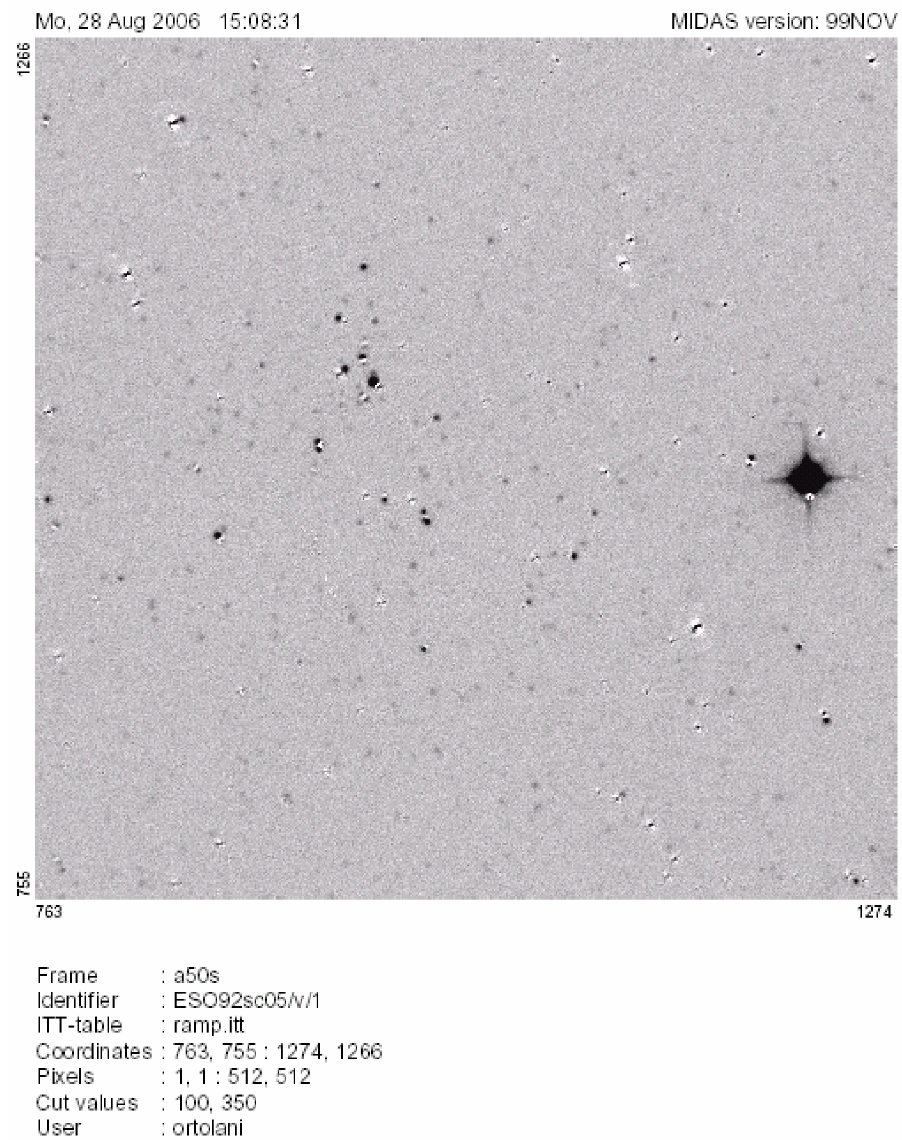
3) Daophot offers also the possibility to add artificial stars and to measure them simultaneously to the original stars.

4) Finally the dispersion of the data due to the errors can be derived from astrophysical considerations (for example from the dispersion of the CMDs).

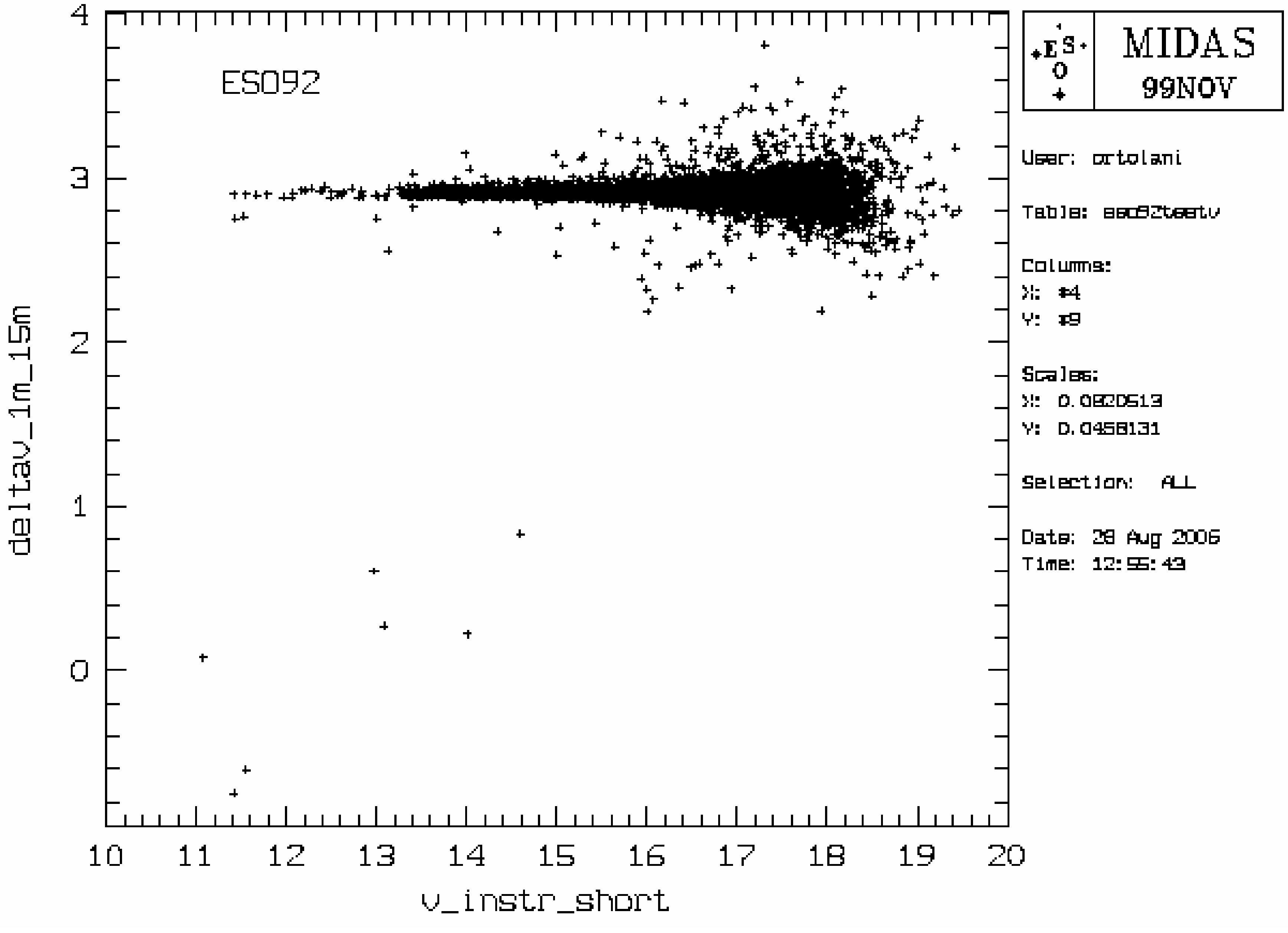
Example of an easy reduction: the relatively low density stellar field in the cluster ESO92. 60 sec. V exposure.



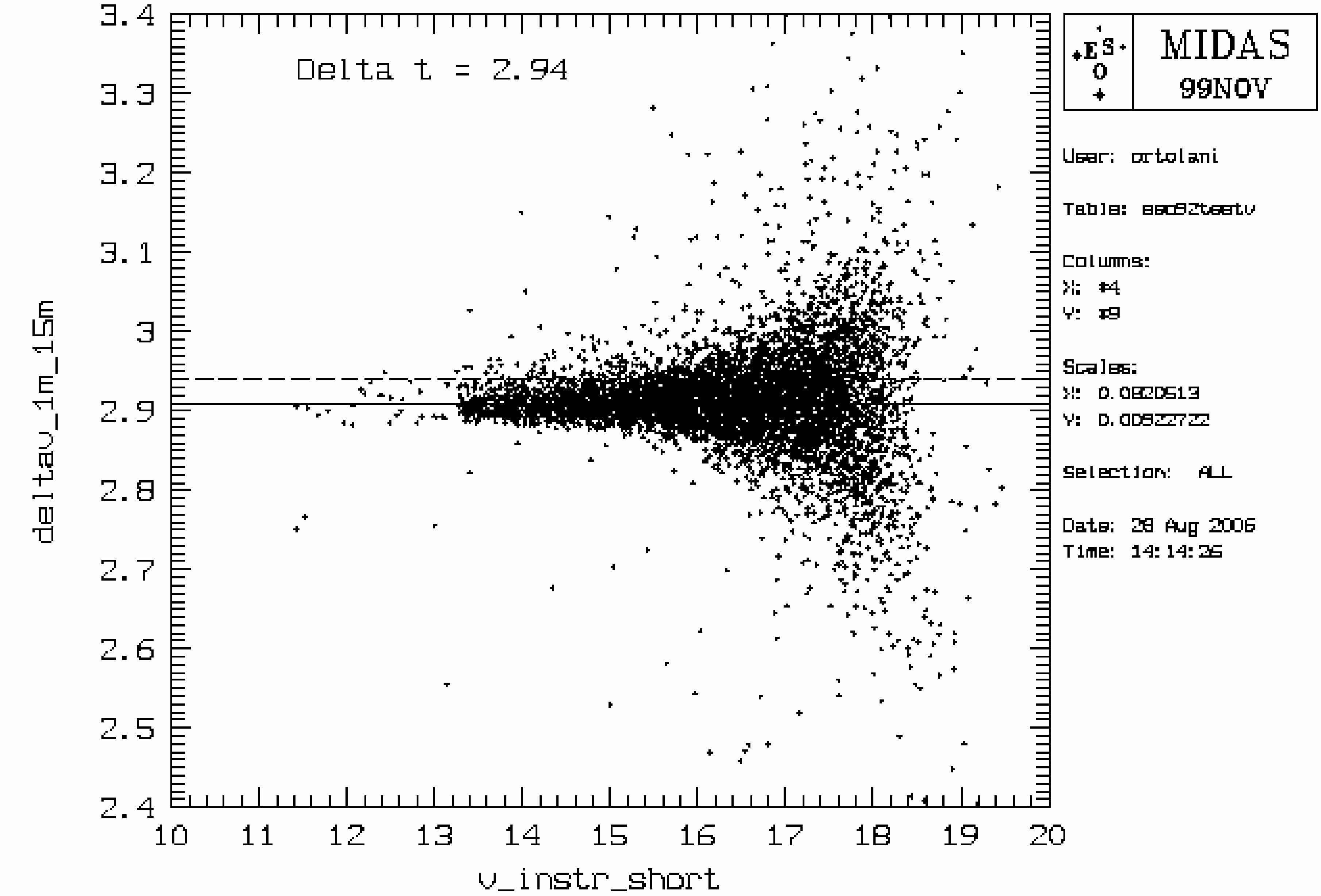
Subtraction of the detected stars



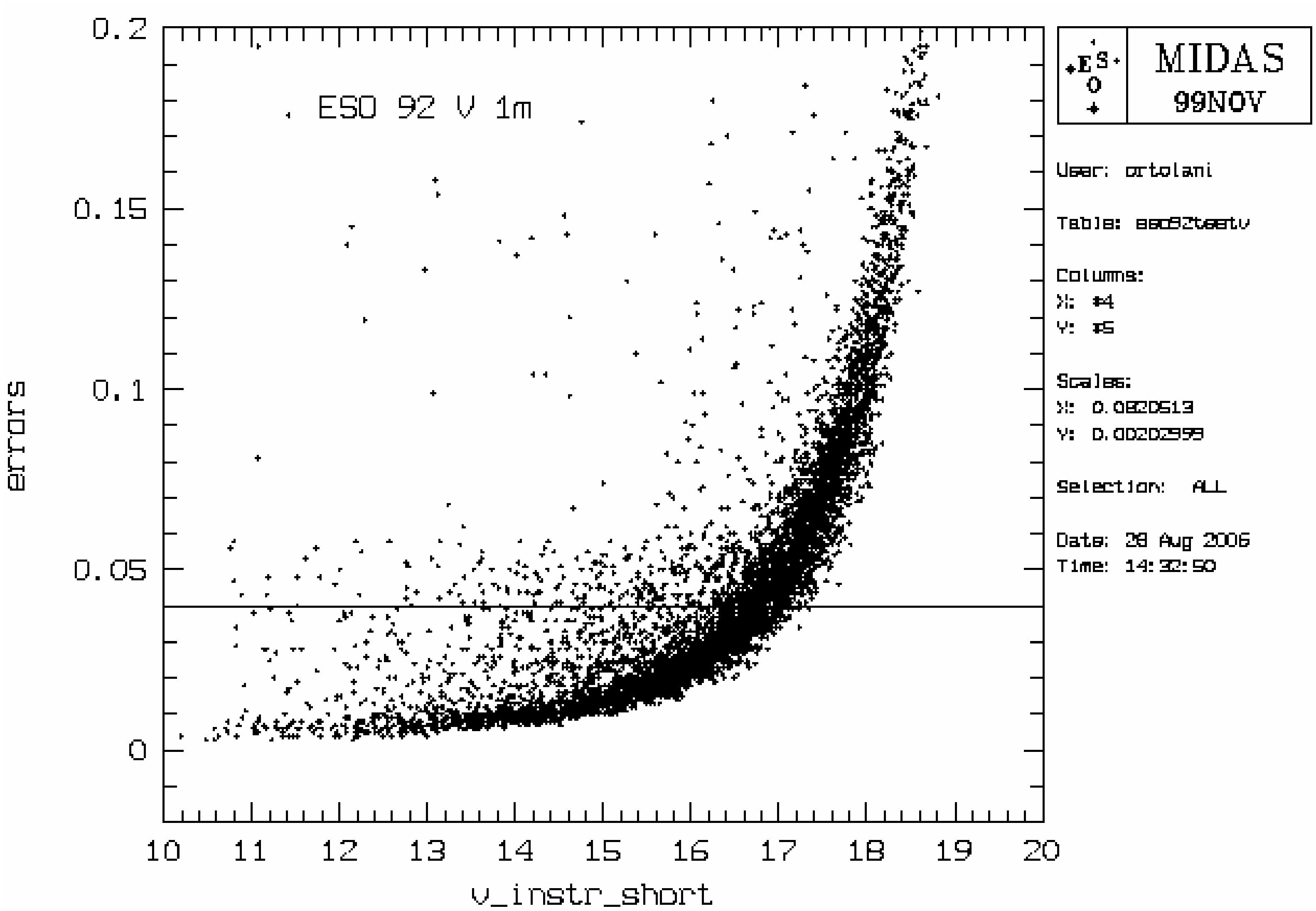
Frame to frame difference: some large deviations for bright stars: overestimated in the deep (15 min.) image, close to saturation ?



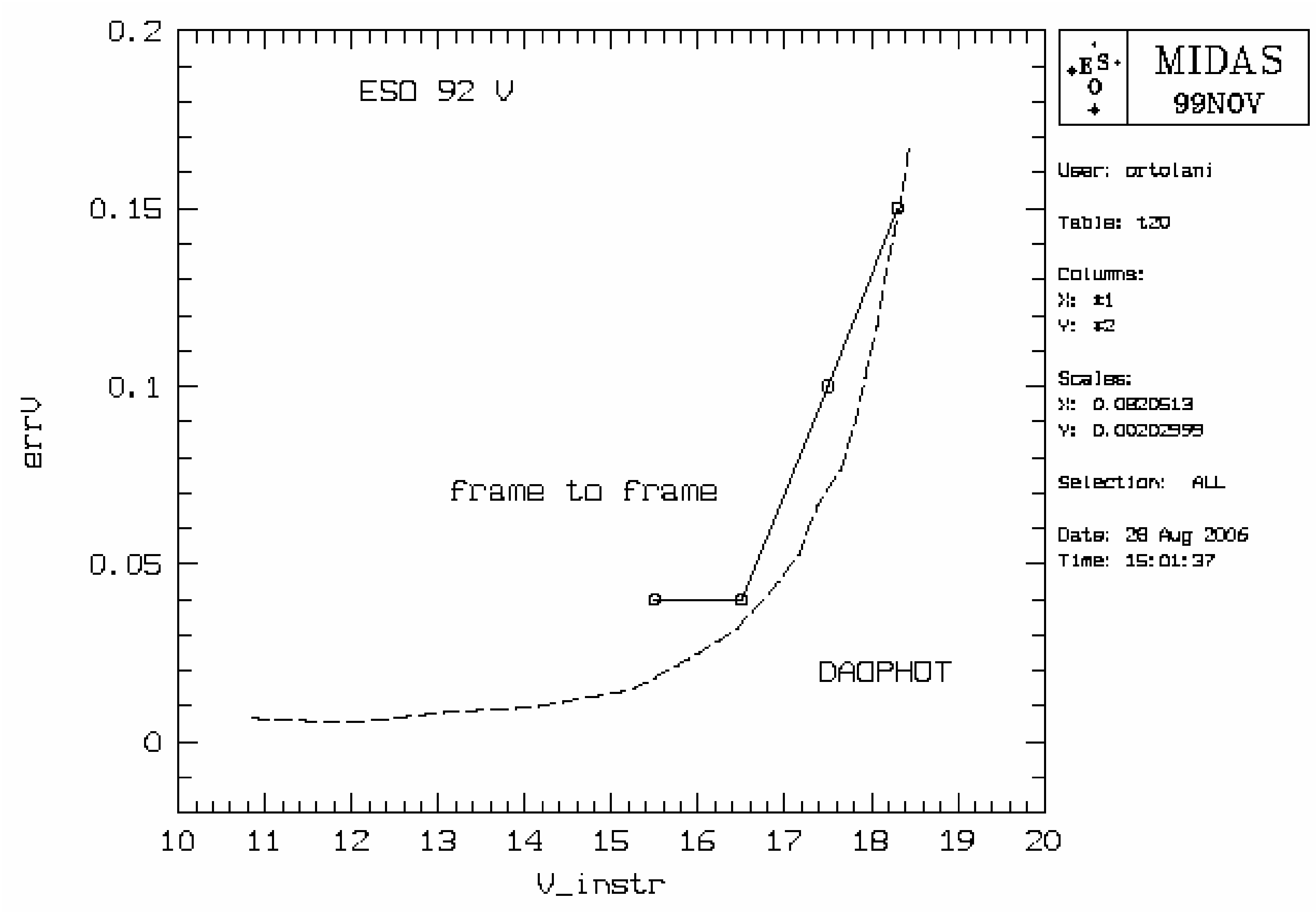
The errors in the frame to frame comparison have a lower limit around 0.04 mag.



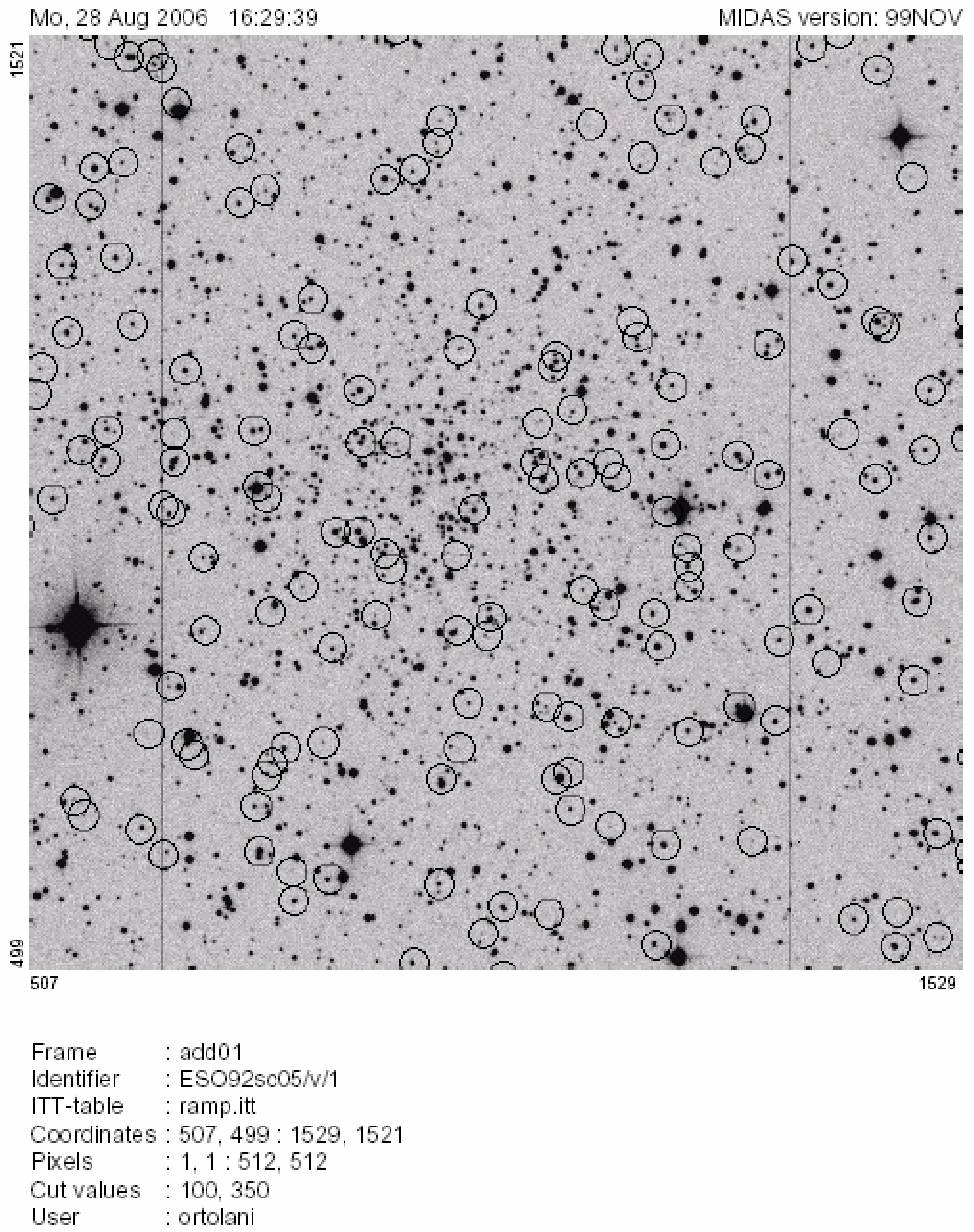
For about half of the measured stars daophot gives errors below 0.04 and many bright stars have less than 0.01 mag. !



Frame to frame vs. daophot (poissonian) errors: what are the real errors ?

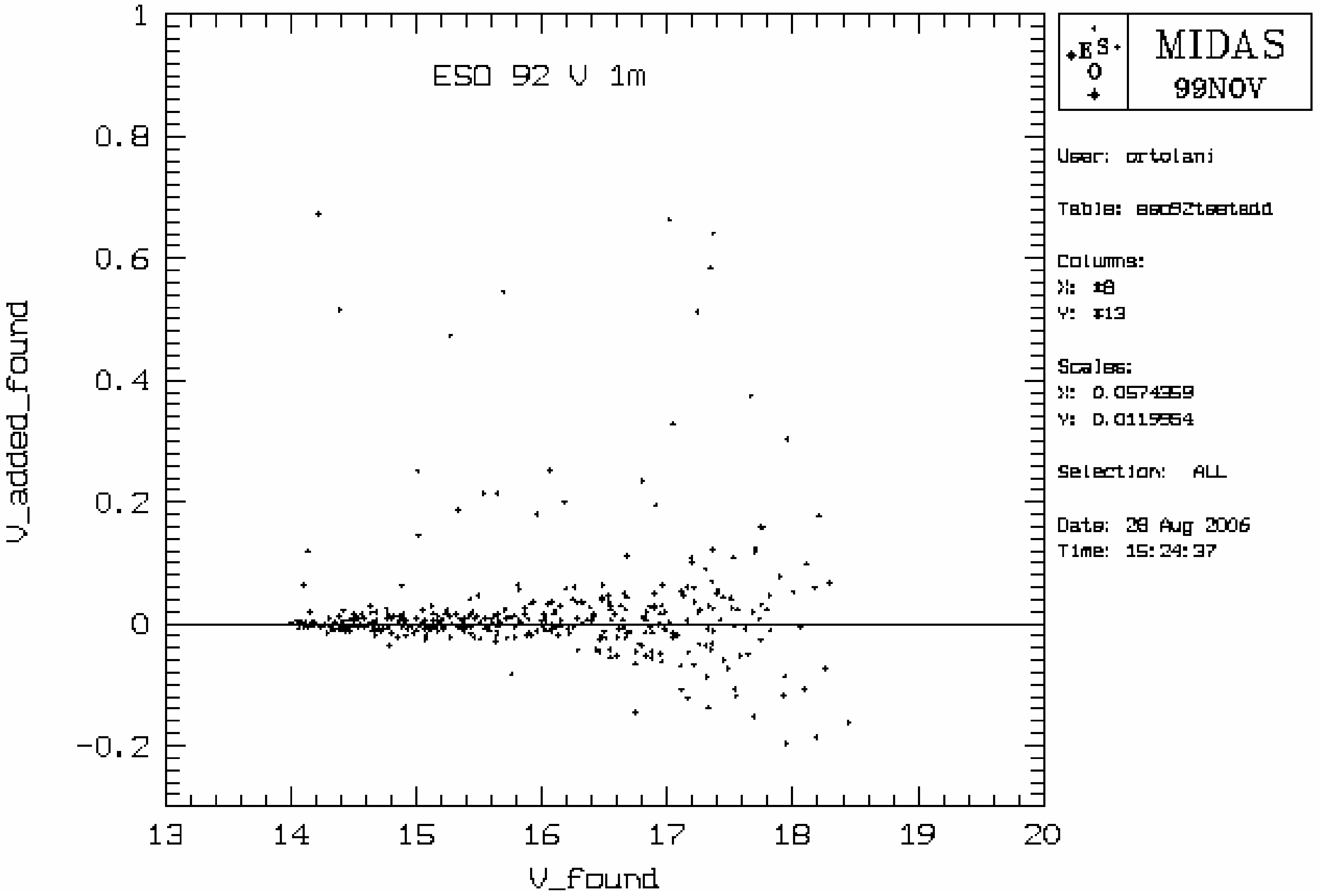


A FURTHER TEST: ADDED STARS (within circles)

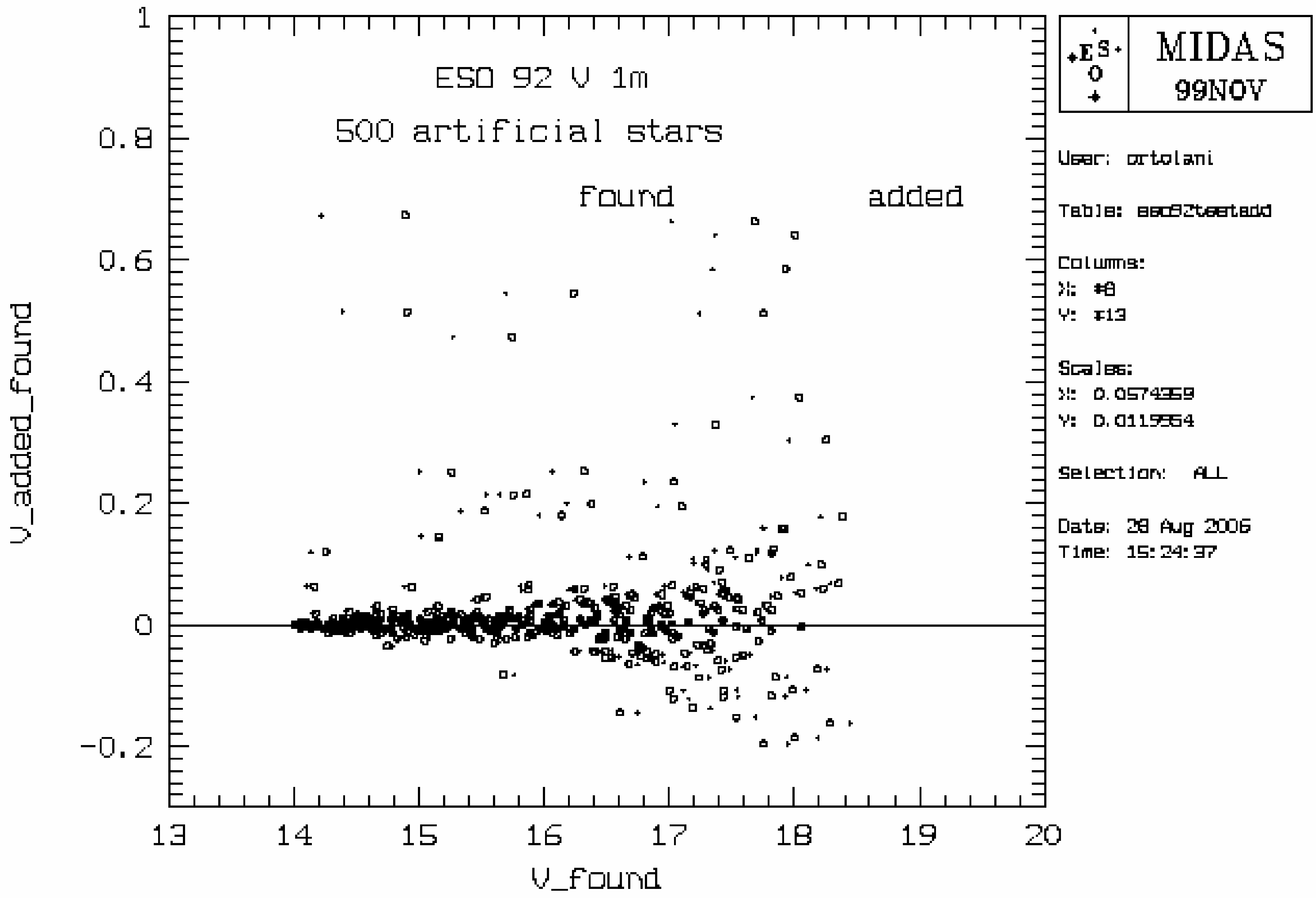


Asymmetric distribution of the errors (orig. magnitudes – measured).

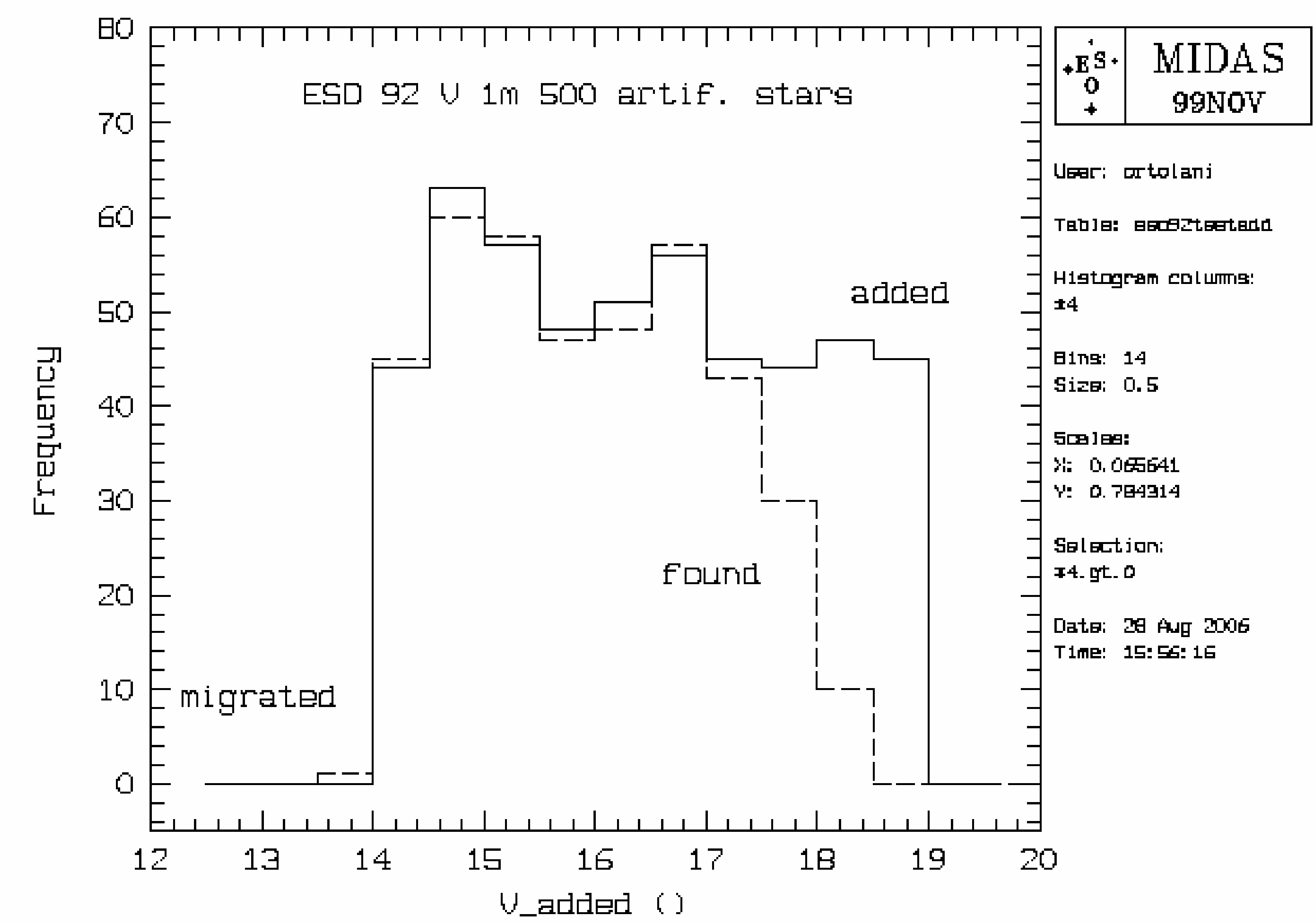
An unexpected result: the measured stars are statistically brighter than the original ones ! There are some large deviations, up to 0.7 mag. WHY ?



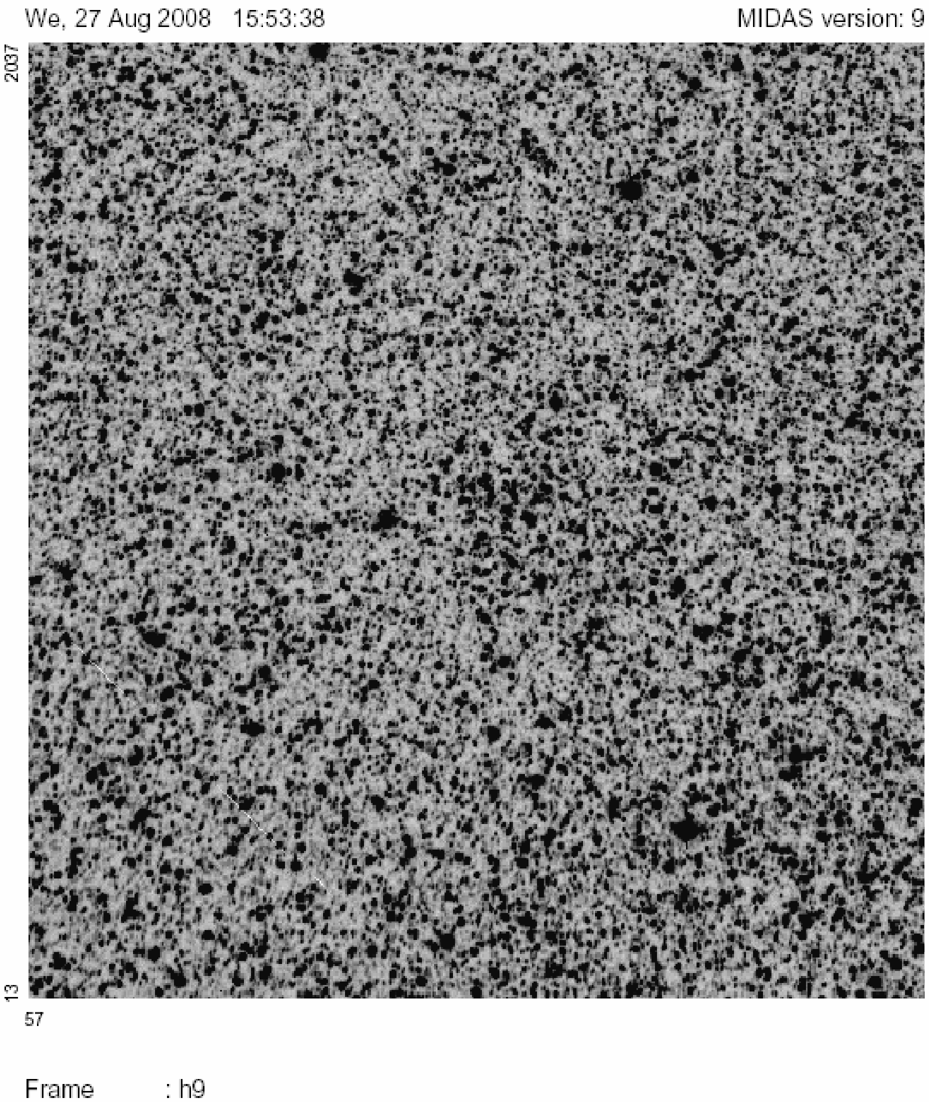
Measured stars with large deviations are systematically brighter than the injected ones: blends ?

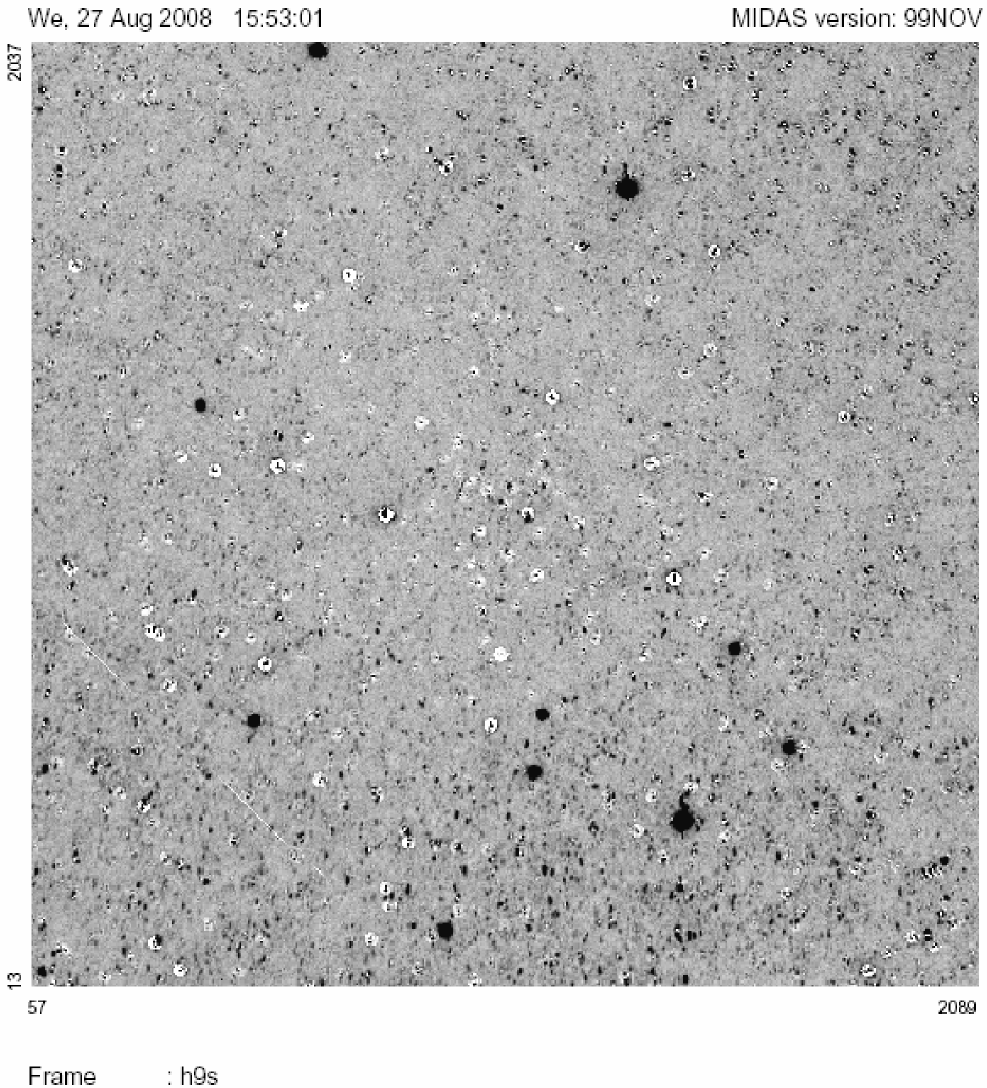


Completeness check: the magnitude migration effect of the artificial stars



A difficult case: a crowded field with a variable PSF





Calibration of extended sources

The calibration for extended sources is still based on standard stars. The basic concept is that the flux of the star is compared to a fixed area.

Example: the sky background

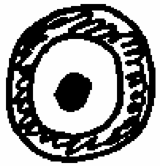
$$Sky(int./unit\ area) = (1/pixel\ area) \times I_{sky}$$

$$m_{sky} = -2.5 \log Sky \qquad \text{(instr. mag./unit area)}$$

then use standard transformations.

Wide band calibrations are very difficult if the passband of the system is not standard.

ANALYSIS

	DAOPHOT	ROMAFOT	INVENTORY
SKY :			
ANAL. :	MULTIPLE FITTING ADD/DELETE COMP.	MULTIPLE FITTING NO ENTRY CHANGES	ITERAT. CLEA./SUBTR. ADD/DELETE COMP. GALAXY DETECTION
PSF :	ANAL. (CENTER) EMPIR. (WINGS)	ANAL. (MOFF. OR GAUSS.)	EMPIRICAL
	• MANUAL	MANUAL	• MANUAL OR AUTOM.
	- SLOW IN CROWDED FIELDS	VERY SLOW IN CROWDED FIELDS	VERY FAST IN CROWDED FIELDS
	- LIMITED INTERACTIONS	- MANY INTERACTIONS	- TWO COMMANDS ONLY
SENSITIV. TO INPUT PARAM. :	LOW	HIGH	VERY HIGH