Paris DUEL Summer School 2009

Lecture I: From CCDs to Science - The `SExtractor` program

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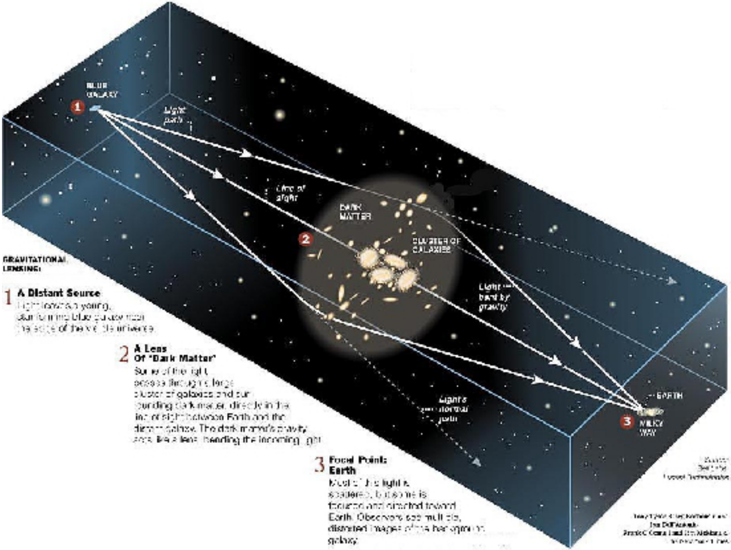
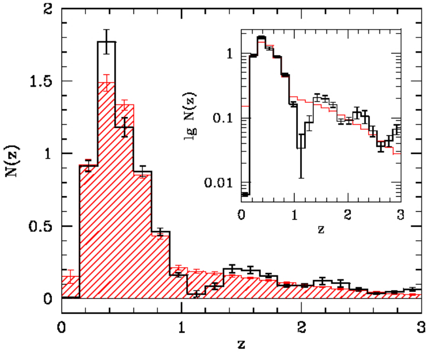
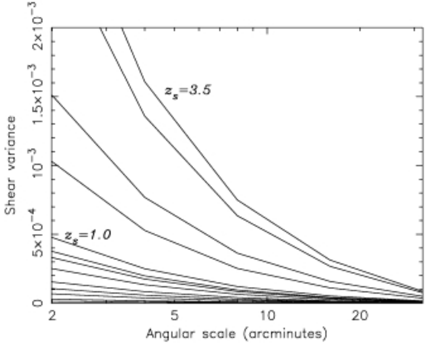
The third dimension



The third dimension



Hetterscheidt et al. (2007)



Barber (2002)

For lensing studies we primarily need knowledge on the *redshift distribution* of background sources and associated errors!

Multicolour data - Photometric Redshifts

What is this week about?

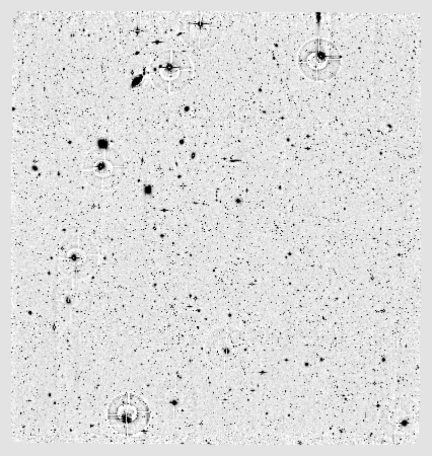
Topics we would like to cover:

- How to arrive from raw, Wide-Field Imaging observations at science-ready images (data reduction, reduction pipelines)
- How to extract a weak lensing catalogue (shear analysis, shear extraction algorithms)
- How to extract photometric redshifts from multi-colour observations (photometric calibration, multi-colour photometry)

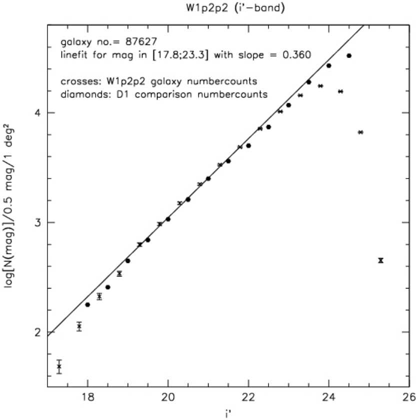
My goal is that you can perform basic multi-colour analyses on science-ready ground-based images (pulic data such as CARS, CFHTLS, COSMOS, GOODS)

Ready-to-use science images

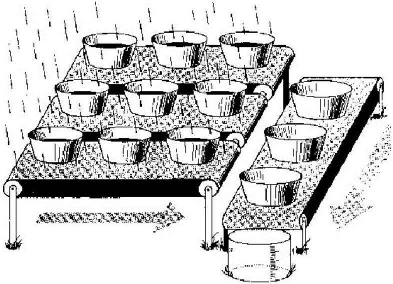
Pixel data

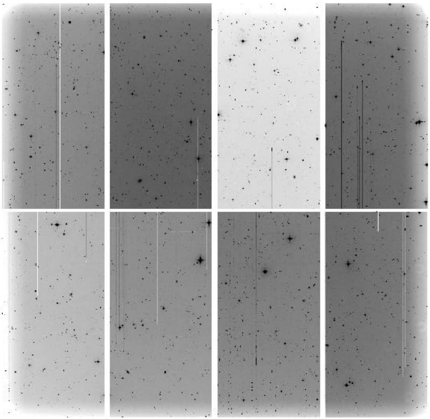


Quality Control



CCD observations

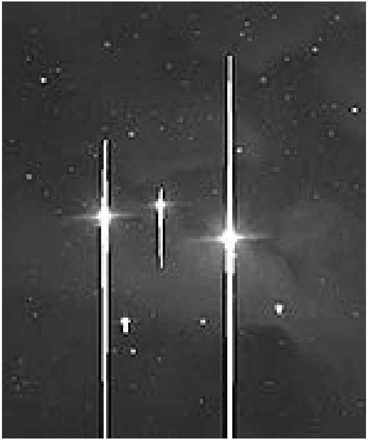




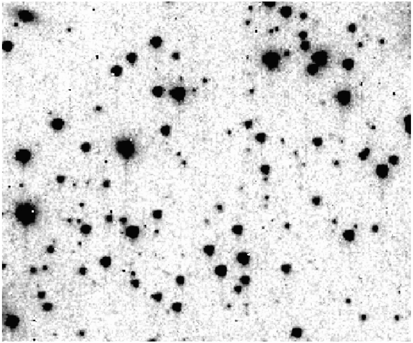
Important characteristics: *linear* device, Full well capacity (150000 e-); maximum digital units (15 bits, 16 bits), gain ($\approx 1 - 4$)

CCD features

Blooming



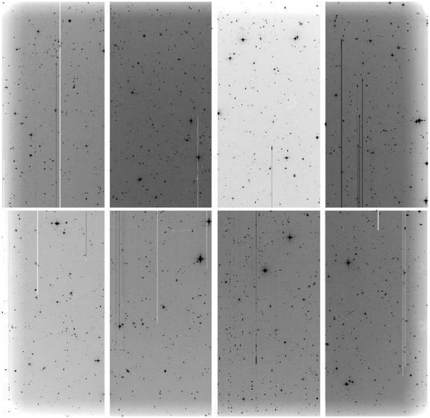
Charge Transfer Effiiency



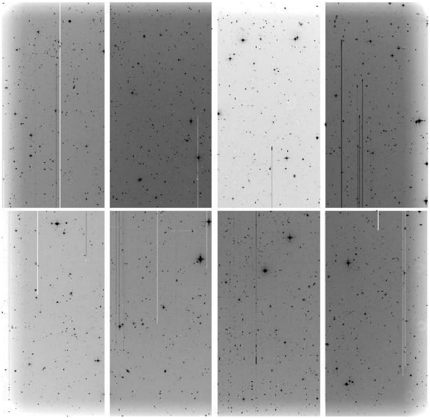
The WFI@ESO2.2m Wide-Field Imager

WFI was installed in December 1998

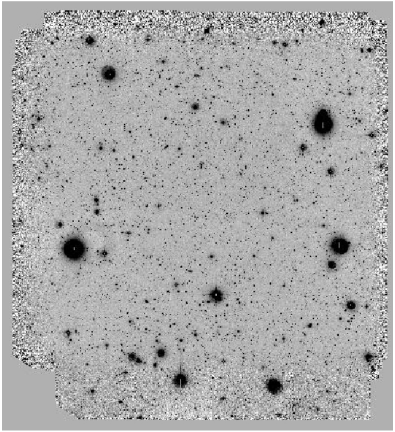
- 8 chips
- $\approx$ 8k$\times$8k pixels
- Pixel scale $0\overset{\prime\prime}{.}238$
- Field-of-view: $\approx 34\overset{\prime}{.}0 \times 34\overset{\prime}{.}0$
  (the area of the full moon)
- File size: 256MB (float)
- Geometric distortions, different gains, gaps between CCDs



Data Reduction



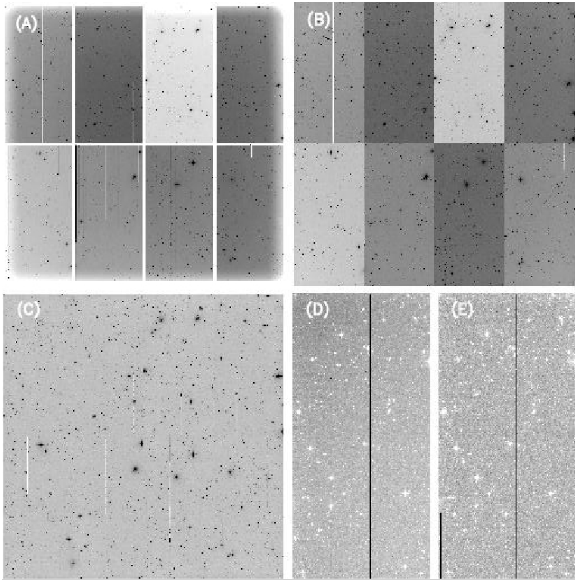
100 images



1 image or 100 images

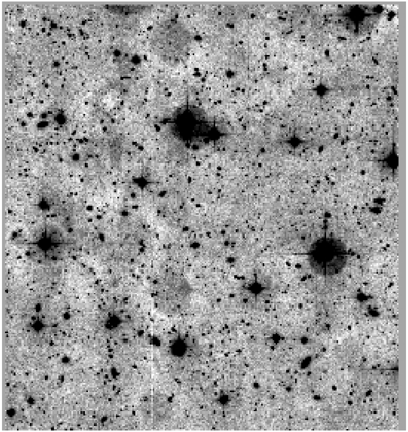
Removal of instrumental signature, Record of image defects, Photometric calibration, Astrometric calibration, (Image stacking)

Removal of instrumental signature

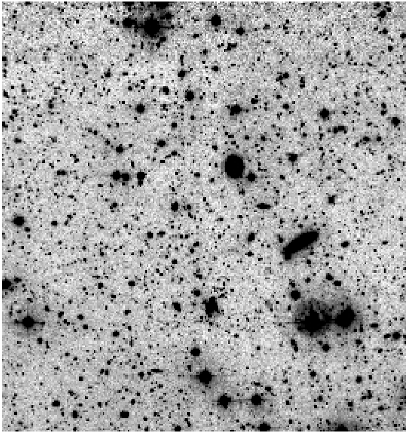


Construction of Calibration Frames

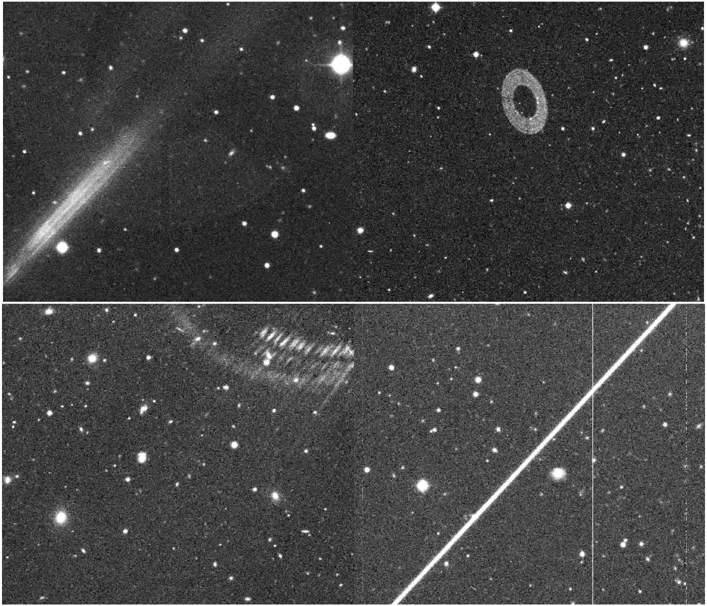
Problematic Flat-Field



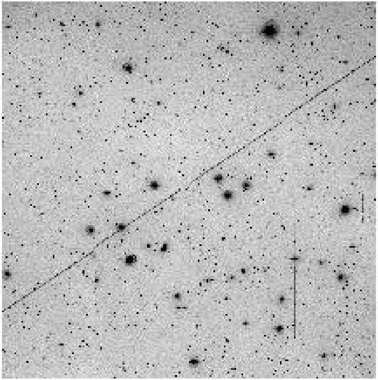
Good Flat-Field

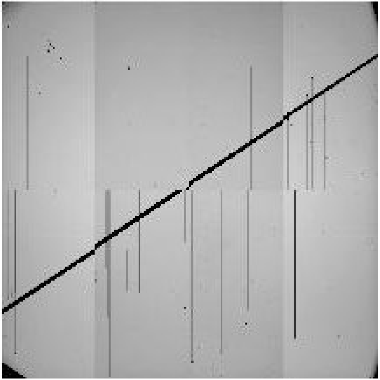


Registration of *defects*



Registration of *defects*

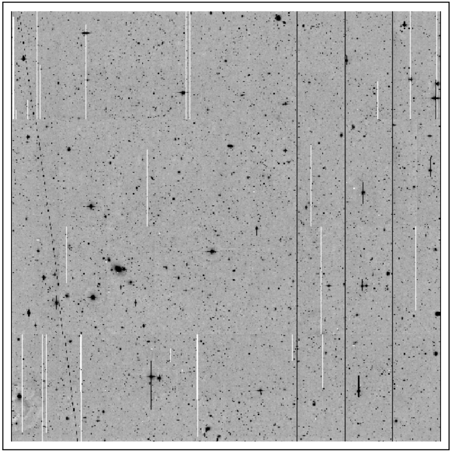




All *defects* in single frames which should be excluded from further analysis are recorded in a *weight image*.

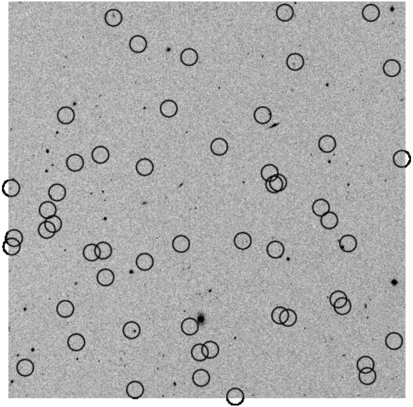
Detrended images

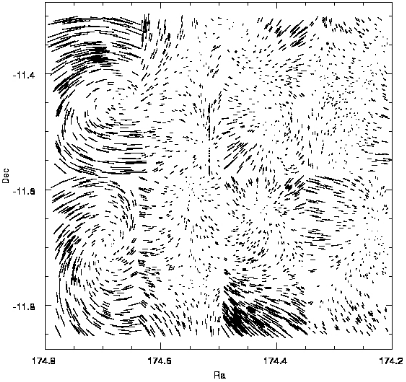
- Bias corrected
- Flat-fielded
- Bad pixel map (no satellite tracks)
- (Absolute Photometric Calibration)



Besids *raw* data, CADC (PanStarrs?) offers *detrended* (preprocessed, Elixir processed) single images for newer instruments (MEGAPRIME, WIRCAM).

Astrometric Calibration





Astrometric calibration first finds a linear shift to an astrometric standardstar catalogue (three to ten sources per sq. arcmin in USNO-B1) and then corrects for higher order distortions.

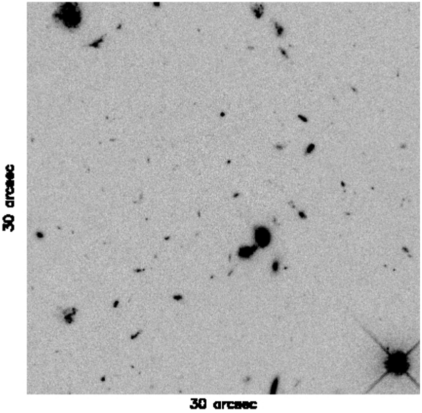
The importance of Astrometry for Lensing

Fluxes, positions and object shapes are measured from moments of the light distribution:

$$Q_{ij} = \int I(\boldsymbol{x})\, W(|\boldsymbol{x}|) x_1^i x_2^j \, d^2x;$$

$$i, j \in [0, 4]$$

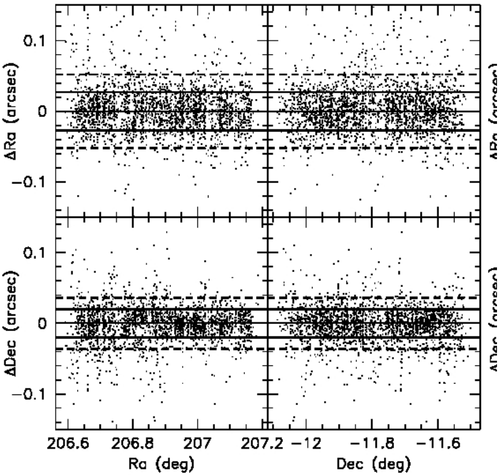
Co-additions (linear processes) have to be accurate enough to preserve light moments at least up to order four.



Galaxies in the Hubble UDF

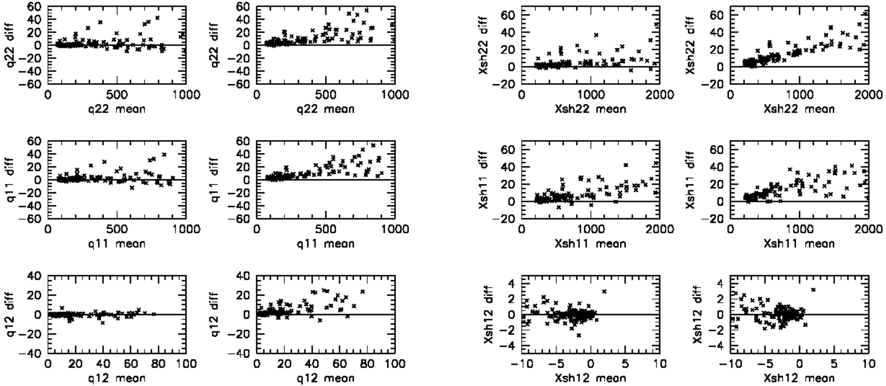
Astrometric Accuracy in WFI data (I)

28 images a 8 chips have been co-added ($\Delta Ra \approx 0\farcs027$; $\Delta Dec \approx 0\farcs02$). The pixel scale is $0\farcs238$.



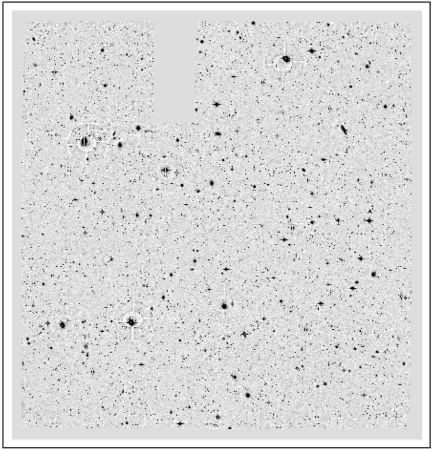
Astrometric Accuracy in WFI data (II)

Second and fourth order moments of the light distribution are conserved in the co-addition with good accuracy (bias of $\sim 1\%$ in 4-th order moments, none in second order moments):

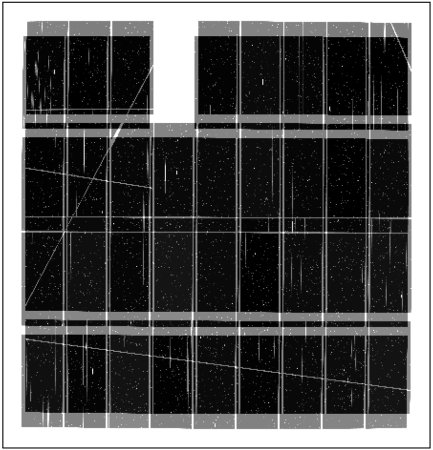


Imaging Products from MEGAPRIME@CFHT

Science Image



Weight Image



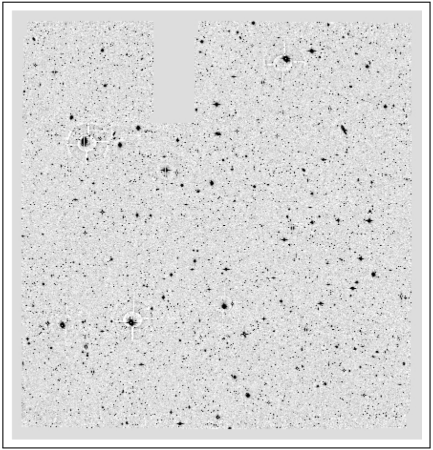
Basic Characterisation of science data: Weight map, Magnitude Zeropoint, Astrometry, Gain, (Flag Map), (Image Masks) ...

Imaging Products from MEGAPRIME@CFHT

FITS Header

```
BITPIX   =                  -32
NAXIS1   =                 5200
NAXIS2   =                 5200
EXTEND   =                    T
NEXTEND  =                    0
EQUINOX  =            2000.0000
RADECSYS= 'FK5      '
CTYPE1   = 'RA---TAN'
CUNIT1   = 'deg     '
CRVAL1   =       3.650000000E+01
CRPIX1   =        9.50000000E+03
CDELT1   =      -5.166666789E-05
CTYPE2   = 'DEC--TAN'
CUNIT2   = 'deg     '
CRVAL2   =      -4.500000000E+00
CRPIX2   =        3.40000000E+03
CDELT2   =       5.166666789E-05
.
.
EXPTIME  =             187951.0
GAIN     =             304481.0
MAGZP    =              25.7087
SEEING   =               0.7719
```

Pixel data



The simplest FITS images consist of a combination of a simple ASCII header and the pixel data.

Learn data processing and data handling - why?

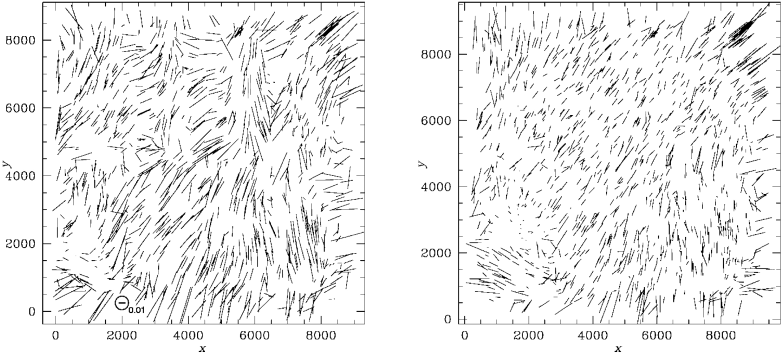
There are many public and calibrated imaging data around (CDFs, GOODS, COSMOS, CFHTLS ...). Why should I deal with data processing?

- You can better make use of already reduced and public data sets
- There are LOTS of excellent lensing and photo-z data in public archives - typically in raw/detrended format
- You will have very good job opportunities in the near future (DES, LSST, satellite missions)
- You know exactly what you did!

PSF patterns in WFI data

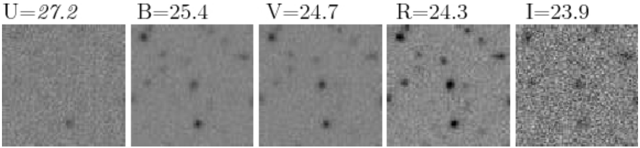
Two astrometric solutions which reproduce well zeroth and first but NOT second order moments:

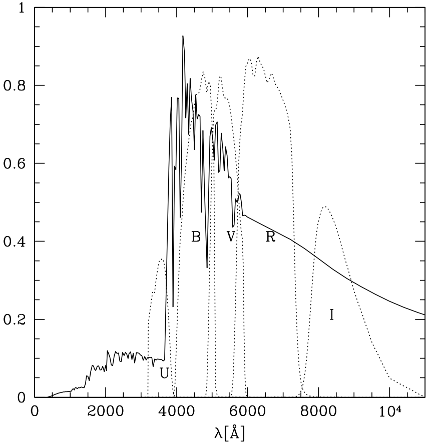
$\Delta m = 0.00 \pm 0.03\text{mag}$
$\Delta x = 0.16 \pm 0.33\text{pix}$; $\Delta y = 0.00 \pm 0.33\text{pix}$



Dietrich et al. (2006)

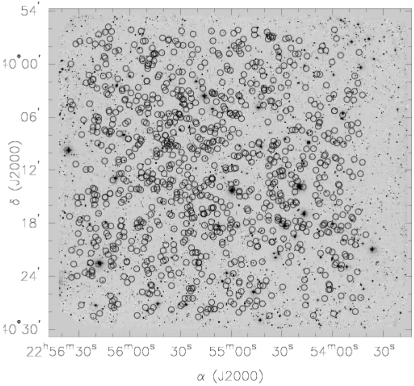
Scientific Project: Lyman Break Galaxies

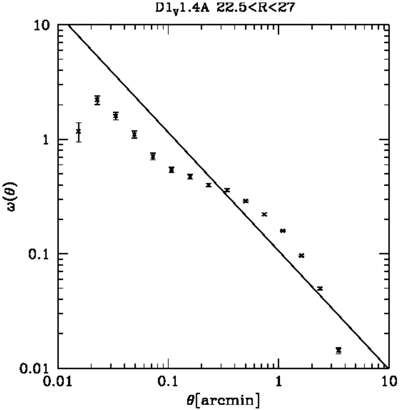




Scientific Project: Lyman Break Galaxies

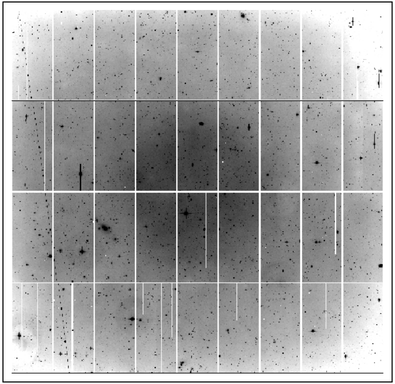
Correlation function of 16000 u^* dropout candidates (first try):

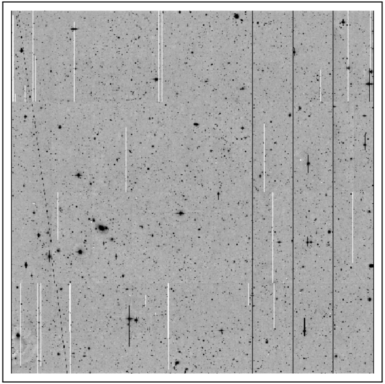




Detrended images

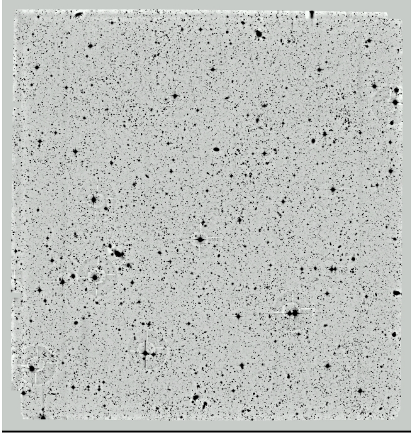
A detrended i-band image: The photometric homogenization leads to a non-uniform background.

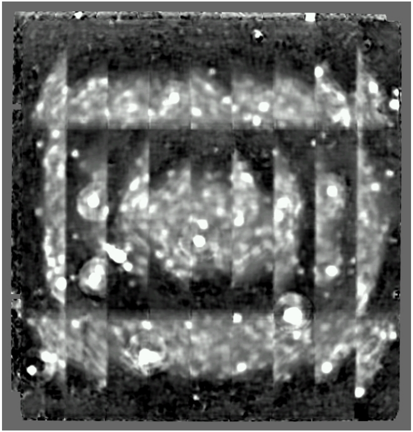




Scientific Project: Lyman Break Galaxies

One- and two-pass sky-background subtraction:

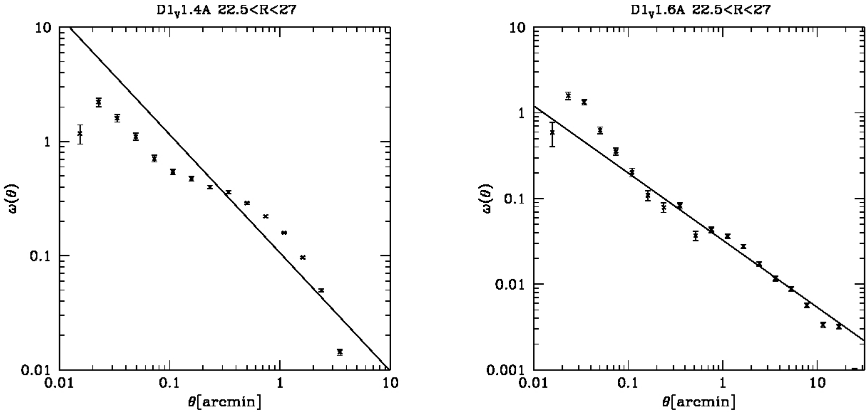




Differences occur because of the non-flat preprocessed images (illumination correction).
The amplitude of the differences are on the 1σ noise level of the original image.

Scientific Project: Lyman Break Galaxies

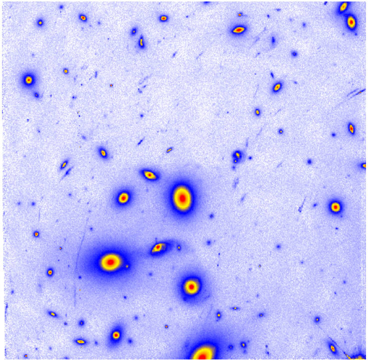
Correlation function of 16000 u^* dropout candidates with two- and one-pass sky-background subtraction:



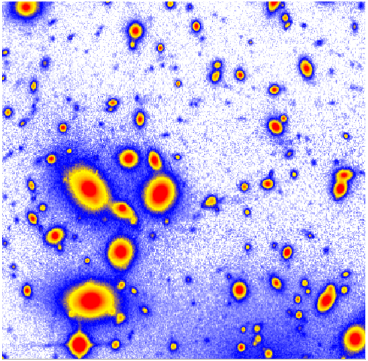
The background fluctuation (together with revised masks) lead to significantly different results !!!

The contents of ground/space images

space-based

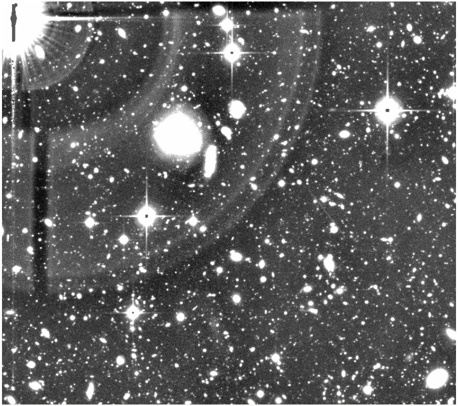


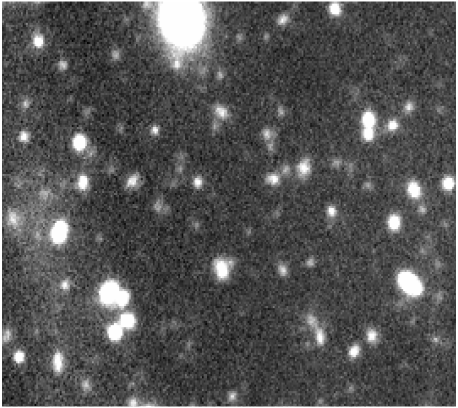
ground-based; 0.6” seeing



It is amazing that we can do lensing from the ground!

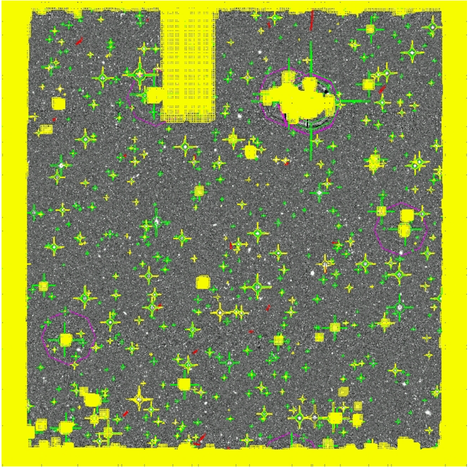
The contents of an optical image





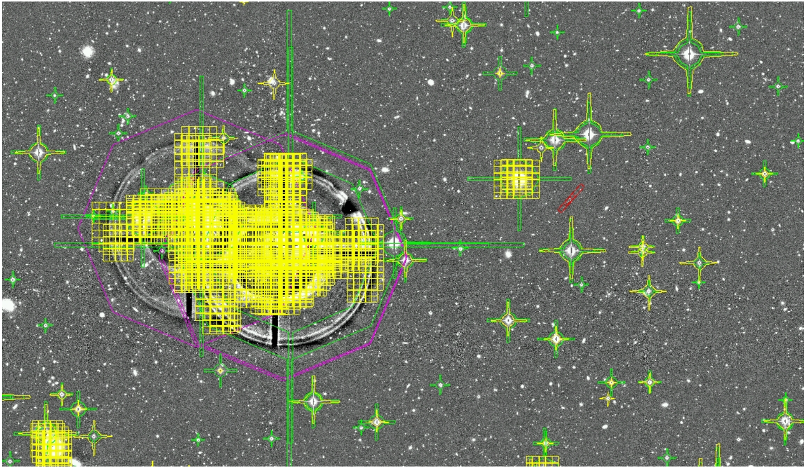
Sky and Noise, galaxies, stars, saturated pixels, stellar haloes
Many of the objects we deal with are confined to very small areas! We often call everything having 3 pixels with 3σ over the sky noise an object!

Problematic areas need to be masked



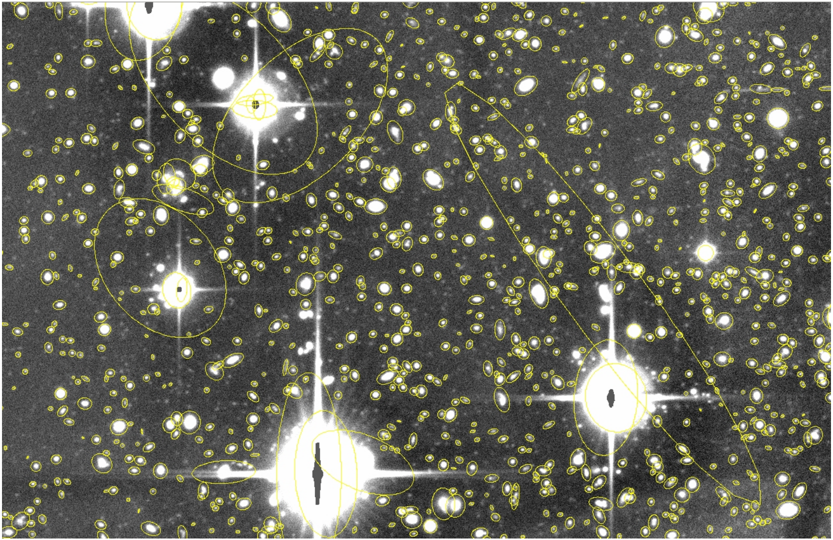
Moderately bright Stars are masked with template masks; large scale defects produce significant jumps in the object number density; each mask is manually adapted at the end! Between 15-25 percent from each image are lost due to masking.

Semi-Automatic Masking of Science Images



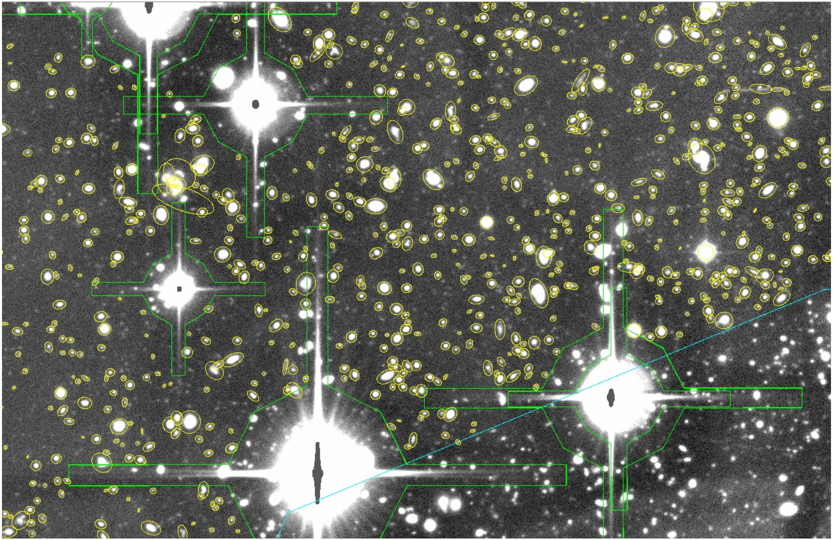
Different standard star catalogues for different stellar populations; masking of large halos and short asteroid trails

Detection of objects without masks



We applied a relatively low (but not uncommon) detection threshhold of three pixels with 3σ above the sky variation.

Detection of objects with masks



Most obvious problems vanish with proper masking

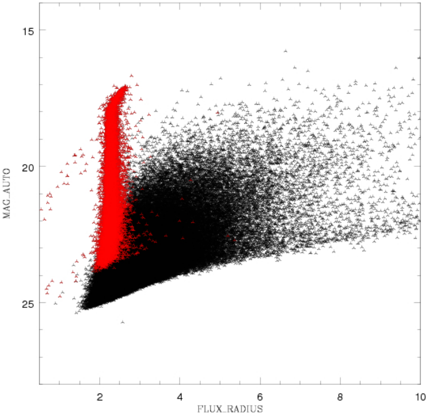
Emmanuel Bertin's `SExtractor` program

- **Extremly** fast and reliable object detector and object analyser for optical images
- Very simple to use (for observers); the number of input parameters which must be adapted is very low
- **Very large** number of object analysis parameters
- **Very large** functionality: usage of weights and flags, double image mode, different magnitude estimates ....
- It can provide the output catalogue in different formats

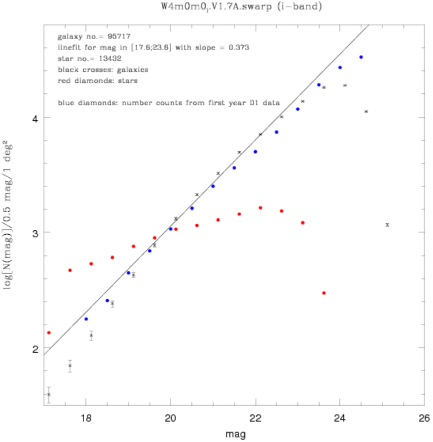
A very good manual of `SExtractor` is:
Benne Holwerda: `SExtractor` for Dummies (`http://mensa.ast.uct.ac.za/~holwerda/SE/Manual.html`)

Simple Quality control plots

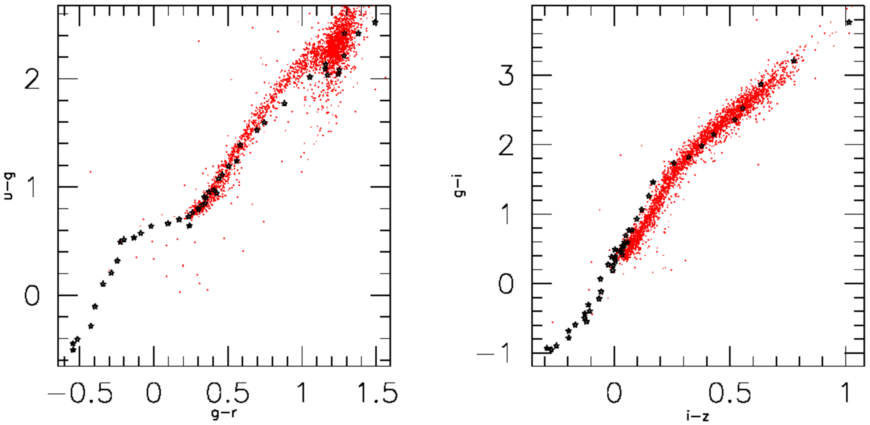
Size-Magnitude distribution



Galaxy Number counts



Verification of photometric calibration

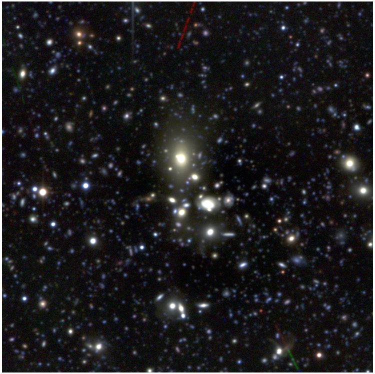


Multicolour data allow the verification of photometric calibration by comparison with model stellar tracks.

The data set (I)

We combined all `high-quality` CFHTLS-D1 data from 03/2003 to 01/2007 within the `CARS` project:

- u^*: 51.5 ks; $0\overset{\prime\prime}{.}95$; $m_{\rm lim}(3\sigma; 2\overset{\prime\prime}{.}0) \approx 28.36$
- g': 44.8 ks; $0\overset{\prime\prime}{.}94$; $m_{\rm lim}(3\sigma; 2\overset{\prime\prime}{.}0) \approx 27.45$
- r': 101 ks; $0\overset{\prime\prime}{.}79$; $m_{\rm lim}(3\sigma; 2\overset{\prime\prime}{.}0) \approx 28.32$
- i': 188 ks; $0\overset{\prime\prime}{.}82$; $m_{\rm lim}(3\sigma; 2\overset{\prime\prime}{.}0) \approx 28.06$
- z': 106 ks; $0\overset{\prime\prime}{.}74$; $m_{\rm lim}(3\sigma; 2\overset{\prime\prime}{.}0) \approx 26.89$

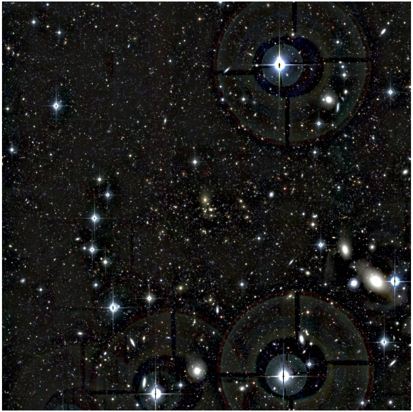


3.1 arcmin

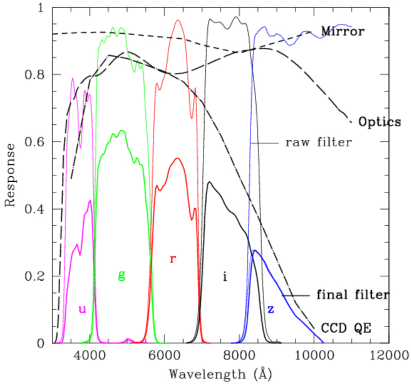
Total area: 16’$\times$16’

The data set (II)

total field-of-view



MEGAPRIME/Sloan filter set



The data set (III)

- The deepest, high-quality images from the ground in five colours!
- Overlap with the VLT Virmos Deep Survey; spectra for photo-z verification
- Reduced CFHTLS Deep and Wide publicly available from various sources:
  - The CARS project:
    `ftp://marvinweb.astro.uni-bonn.de/data_products/CARS`
    `ftp://marvinweb.astro.uni-bonn.de/data_products/CARS_deep`
    `ftp://marvinweb.astro.uni-bonn.de/data_products/CARS_wide`
  - The CFHTLS data from Terapix:
    `http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/cfht/T0004.html`
  - The MegaPipe project from S. Gwyn:
    `http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/megapipe/`