Paris DUEL Summer School 2009

Lecture II: Image simulations with `Stuff/Skymaker`

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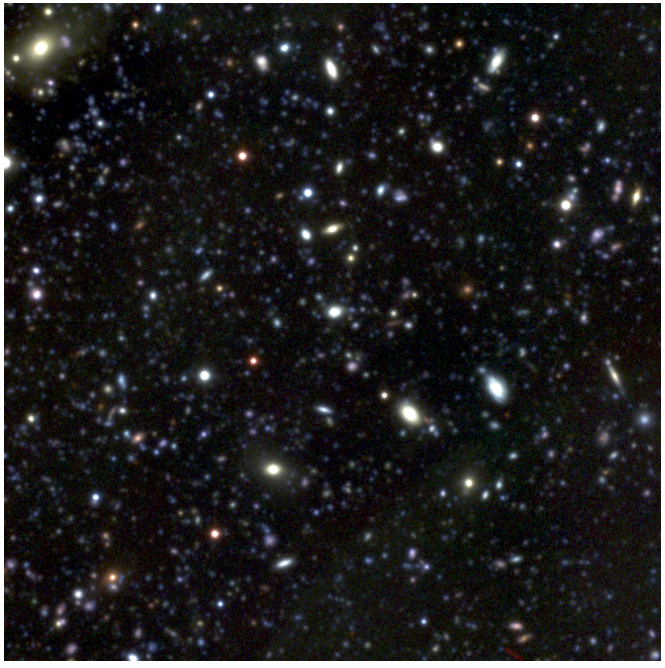
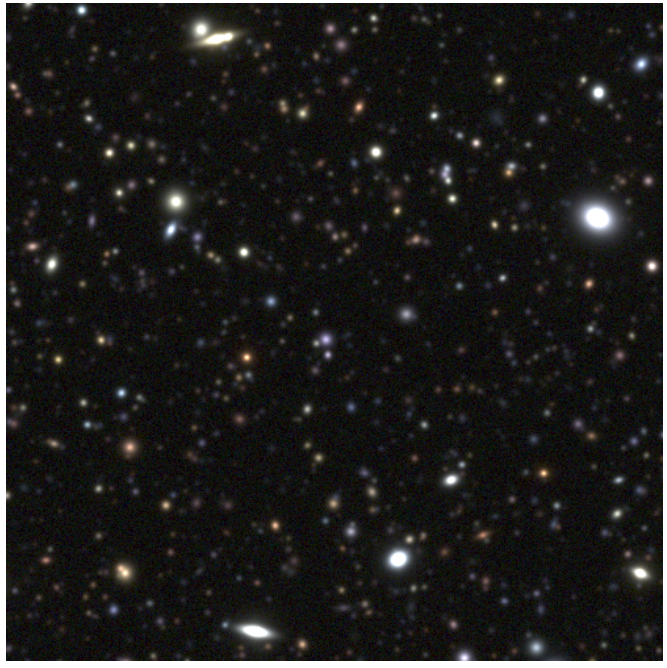
Image Simulations with E. Bertins `Skymaker`

D1 'empty' region ($3'.0 \times 3'.0$)



`Stuff`/`Skymaker` simulation

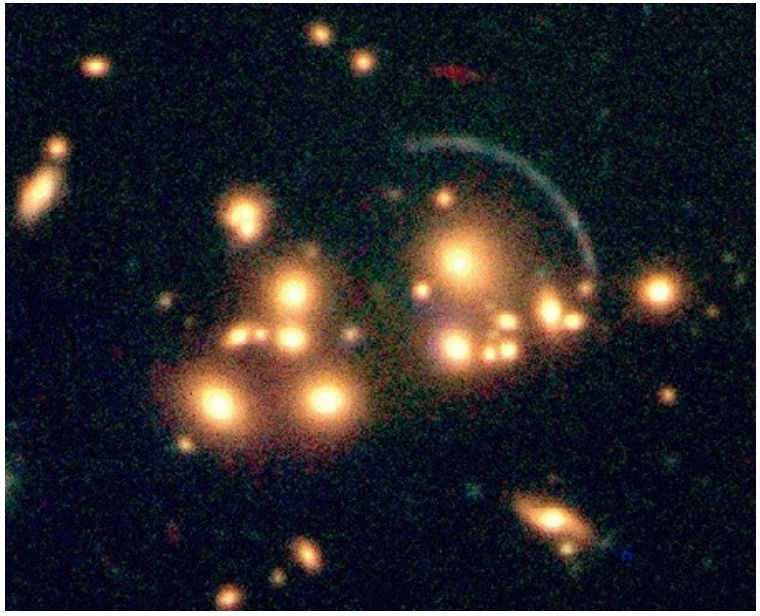


`Stuff`/`Skymaker` (developed by E. Bertin/IAP) allow *relalistic* simulations of the *average* field galaxy population on the basis of object catalogues and FITS images.

Unfortunately no official documentation is available! Most of the following is my understanding from investigating the source codes!

What is it - What is is not

Giant Arc in CL2244



Hoags object

We often try to describe the whole universe and its contents with very few parameters - without taking into account the *details*. So do `Stuff and Skymaker`. The programs are intended to mimic *average* field galaxy populations.
Highlights: Reproduction of galaxy photometry (`Stuff`), the PSF engine (`Skymaker`), reproduction of CCD observations (`Skymaker`)

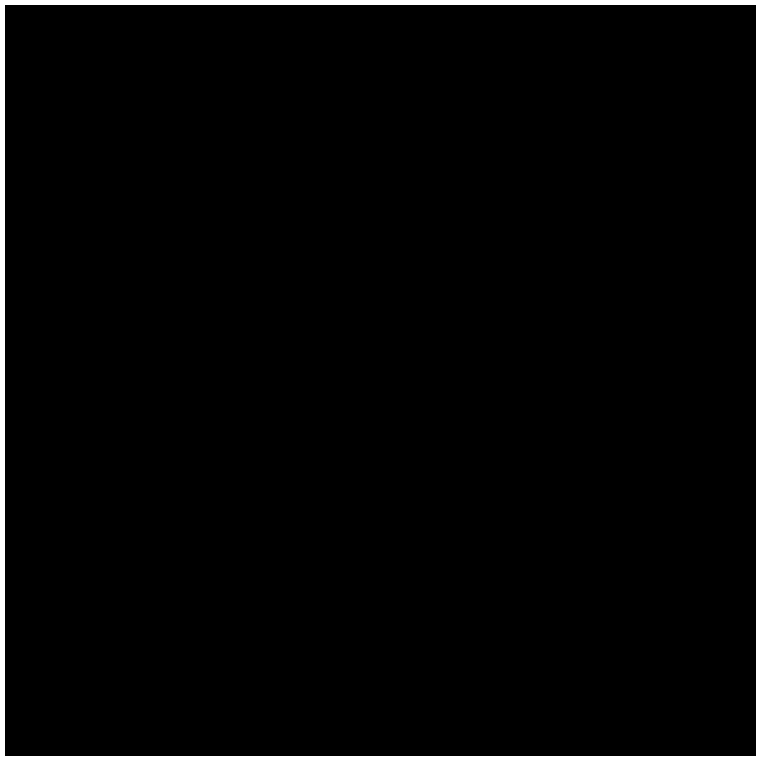
Features and Properties of `Stuff/Skymaker`

- You mainly specify parameters of the telescope, camera and observing conditions (observed passbands, telescope mirror size, seeing, sky-brightness)
- `Stuff` closely mimics basic galaxy properties (distribution of spectral types, properties of galaxy bulge and disk components, observed magnitudes)
- `Skymaker` models galaxies with simple analytical profiles (de Vaucouleurs and elliptical)
- `Skymaker` includes a state-of-the-art modeling of the telecope PSF (Airy Pattern of the telescope entrance pupil, atmospheric seeing, optical aberrations, ...) (currently no variable PSF)
- `Skymaker` mimics various relalistic noise contributions (blooming effects on saturated pixels, sky brightness, pixel noise)

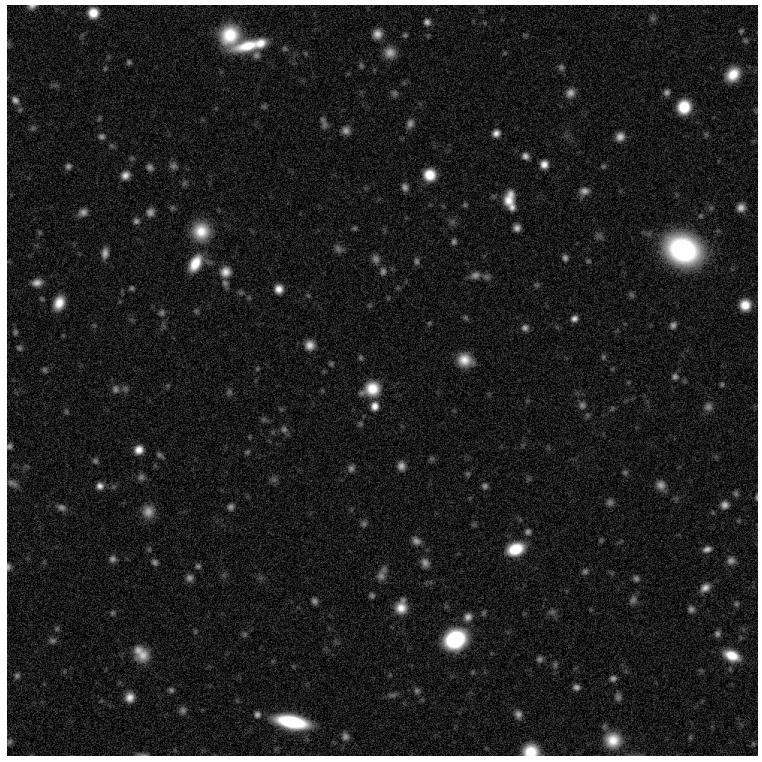
What is a 60000s u-band exposure?

`Stuff` and `Skymaker` are written to simulate *observations*. Without observational background the use of the programs is not always intuitive!

Naive use of `Skymaker`



Observers use of `Skymaker`



What is the result of one continoous 60000s exposure on a 4m class telescope?

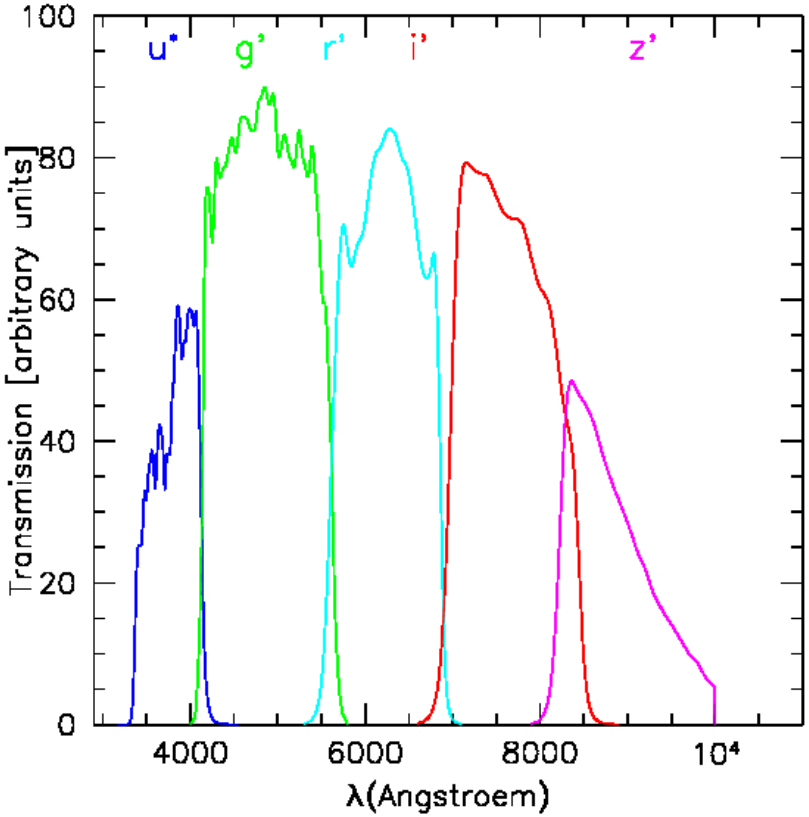
`Stuff`/`Skymaker` Philosophies

- `Stuff` and `Skymaker` are stand-alone C-executables controlled via ASCII-text configuration files (such as other programs from E. Bertin: `SExtractor`, `Swarp`)
- They can easily be integrated in shell script wrappers and pipelines
- `Stuff` is repsonsible for the creation of a galaxy object catalogue in ASCII format. It tries to mimic a simple *field* galaxy population (magnitudes, galaxy sizes, ellipticities, spectral types etc.)
- `Skymaker` creates optical image simulations produced by `Stuff` or *other* programs; optimised to test photometric properties under *realistic* observing conditions (instrument properties, PSF)

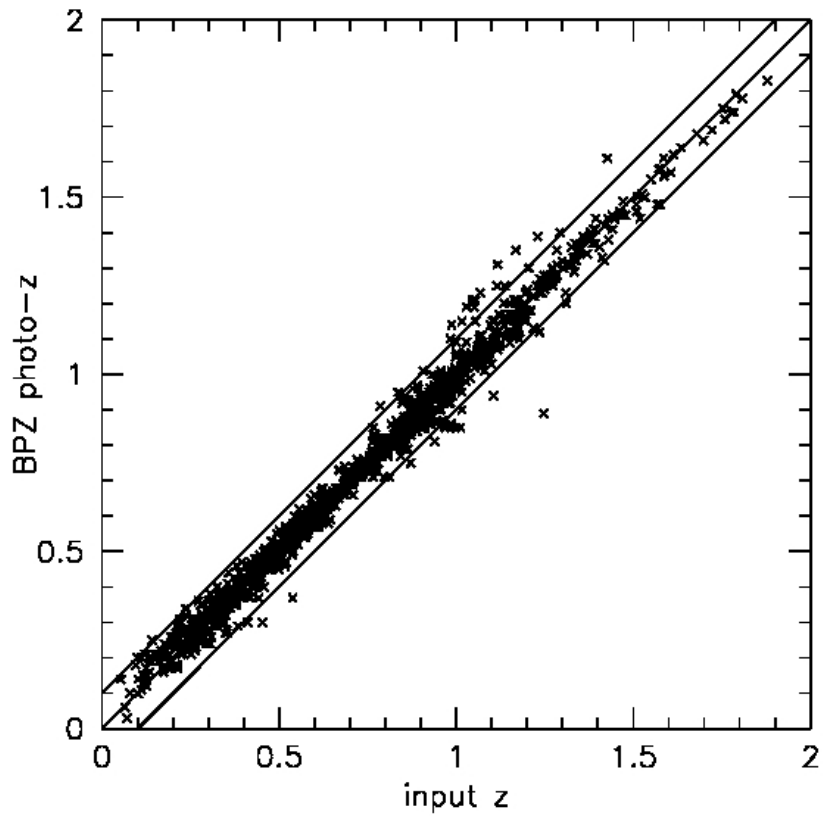
The separation of catalogue and image creation allows us to modify the input catalogue *before* FITS images are produced (effects of gravitational lensing)

Photo-z Simulations with `Stuff` Catalogues

MEGAPRIME filter curves



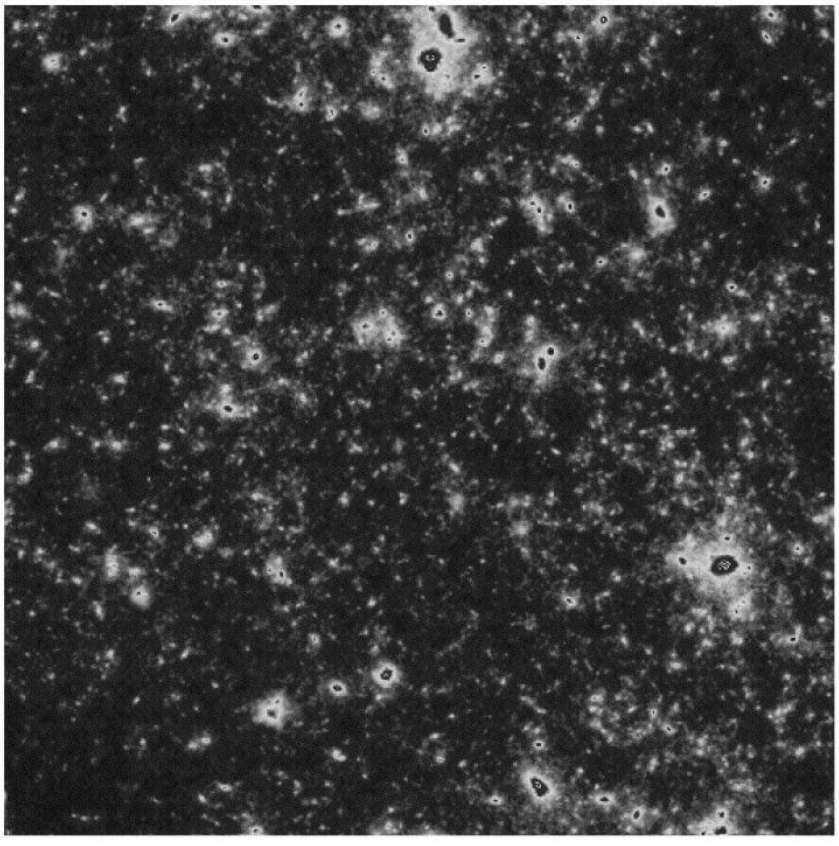
BPZ photo-z estimates



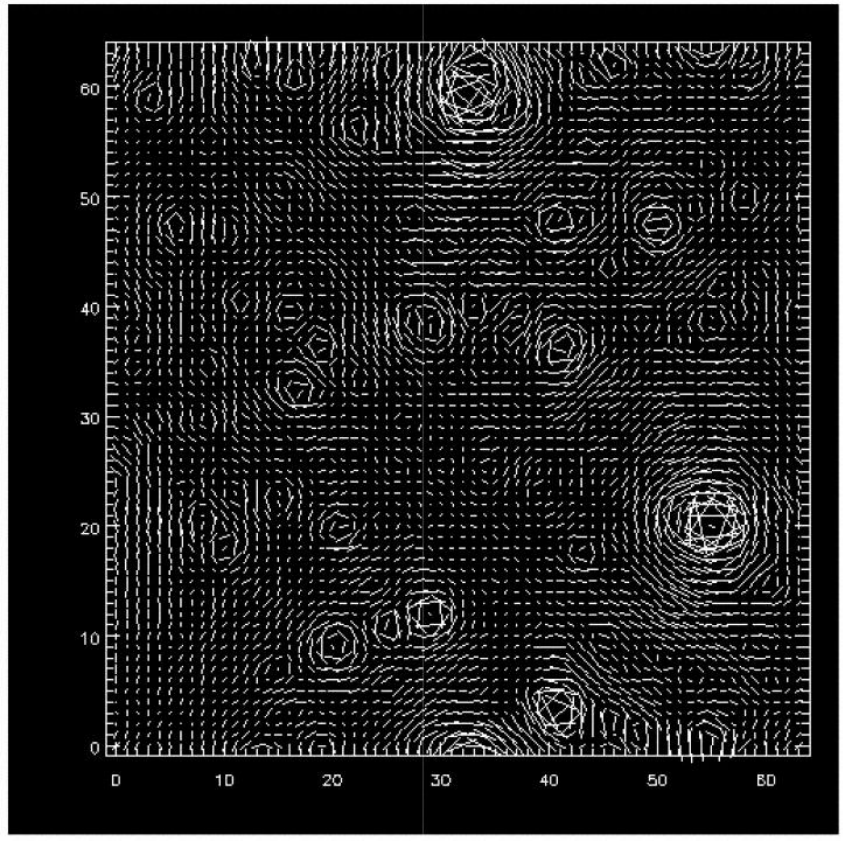
A catalogue with the characteristics of our D1 data was simulated and photo-z were estimated with `Bayesian Photometric Redshifts (BPZ; Benitez 2000)`. This can easily be extended to include `Skymaker` data.

Weak-Lensing Simulations with `Skymaker`

convergence



shear

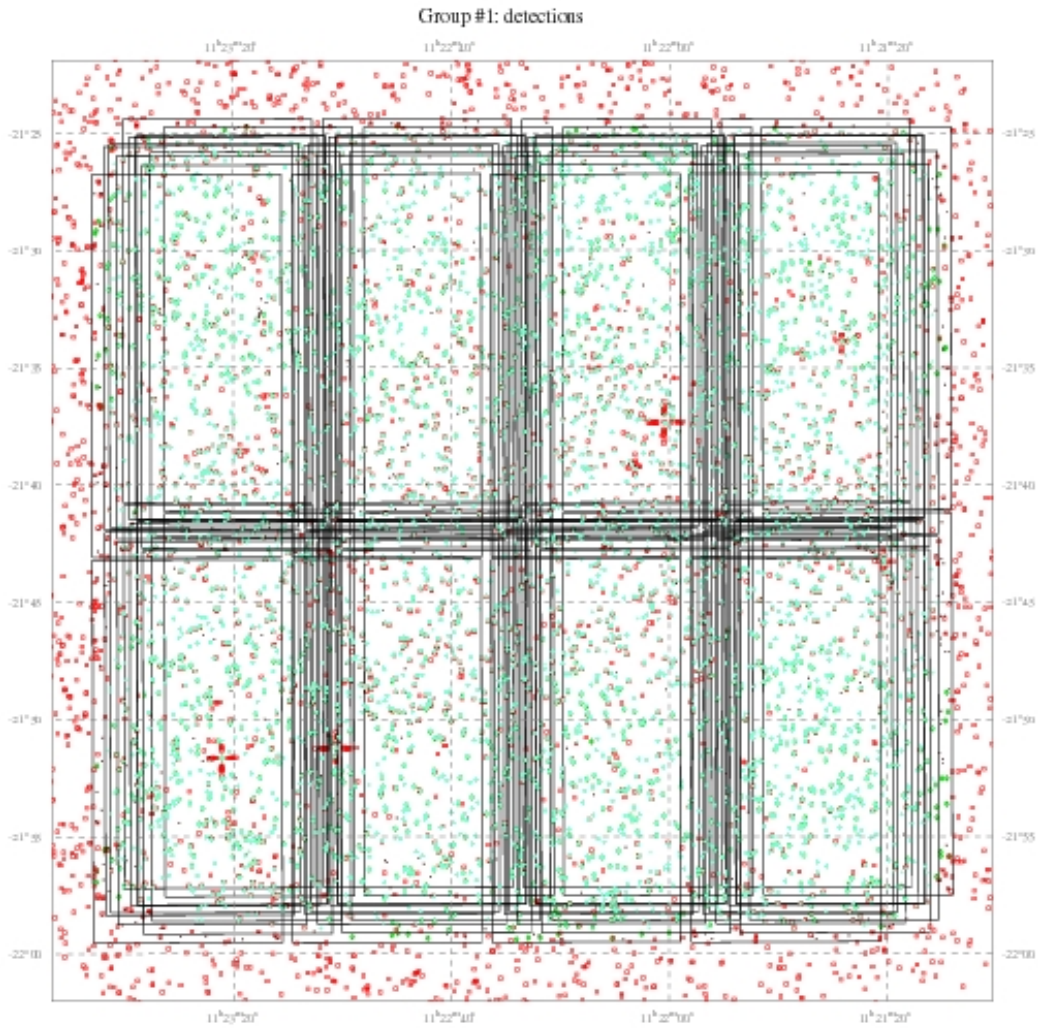


(Figures from Jain, Seljak and White (2000))

Weak lensing can easily be added to the `Stuff` ellipticities. The PSF engine makes `Skymaker` attractive for shear calibration tests (STEP 1!!)

Test of Photometric Pipelines (I)

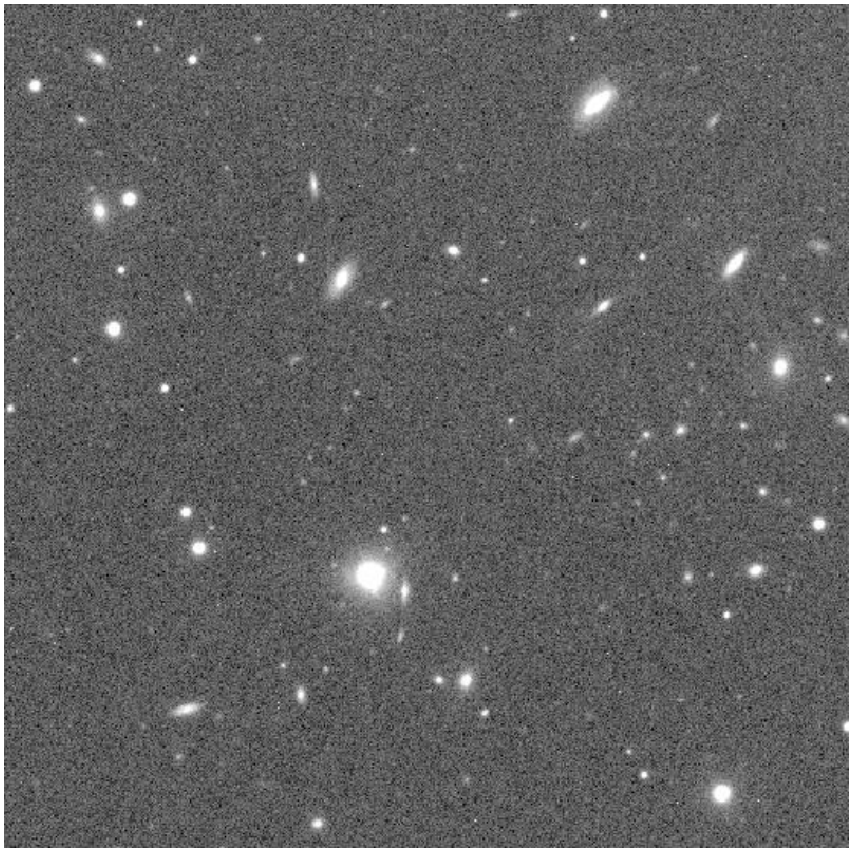
Several dithered observations of a target are *combined* to obtain deep images.



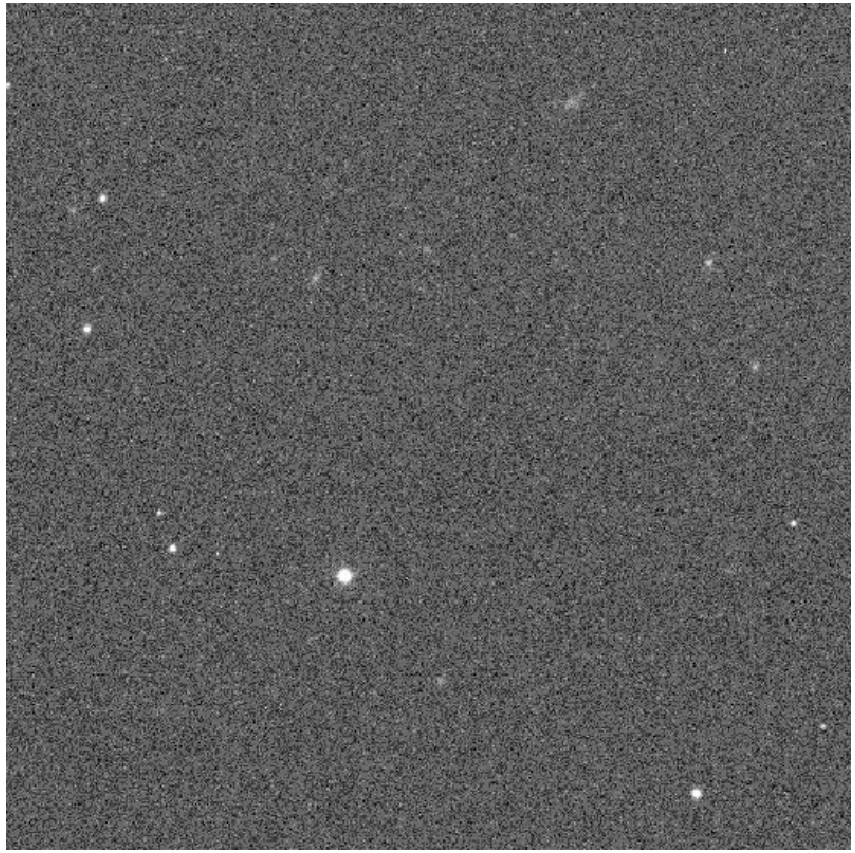
During long campaigns not all of them have good photometric quality

Test of Photometric Pipelines (II)

Good photometric conditions



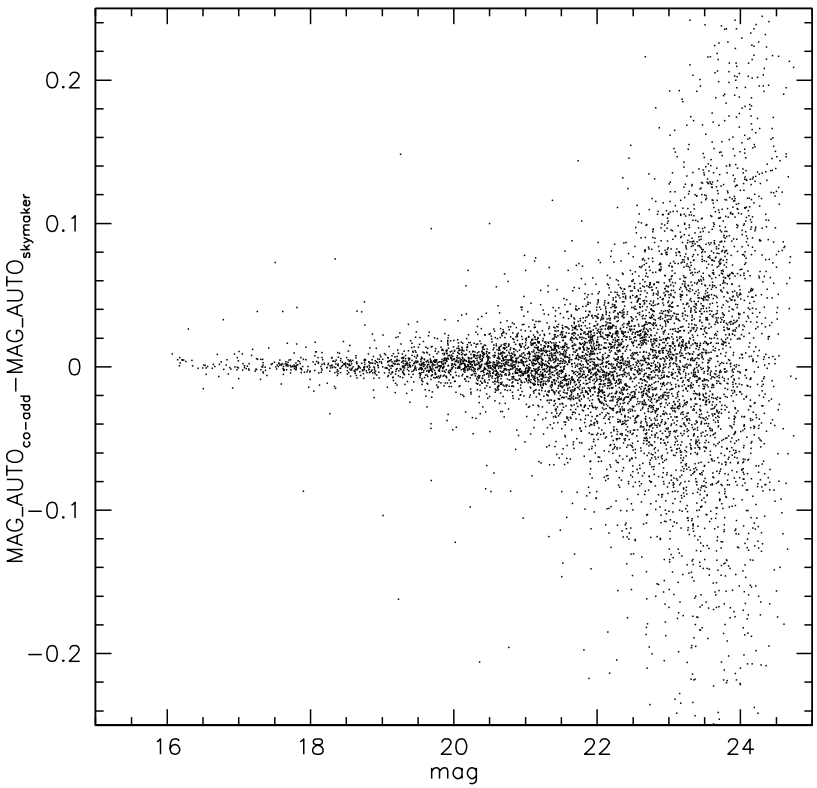
Bad photometric conditions

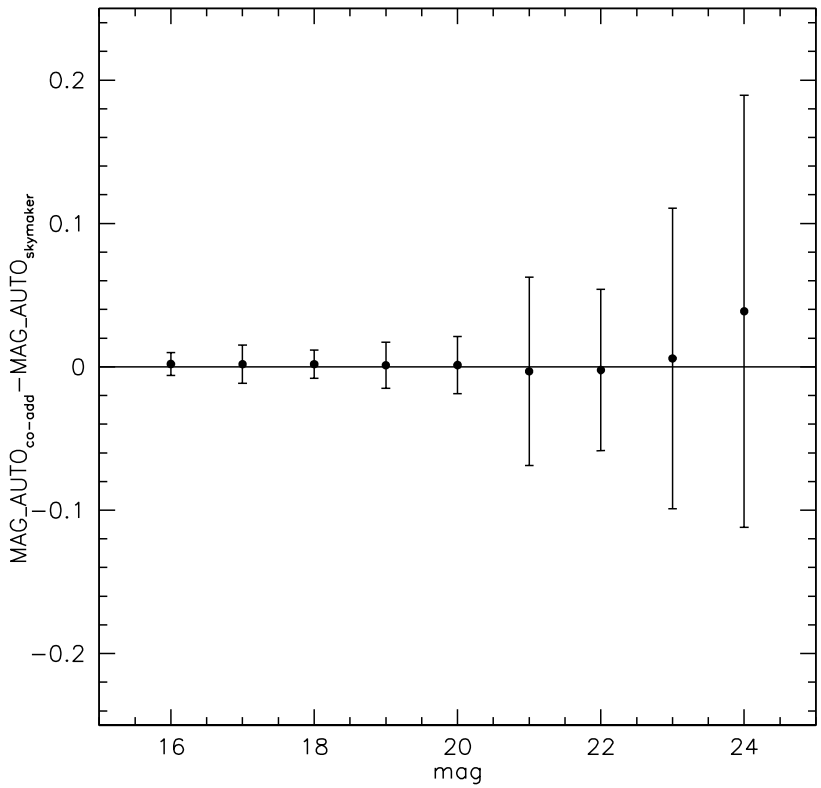


In a stack of many images we need to estimate flux scaling factors to bring all images to the same photometric level. `Skymaker` can help us to evaluate the accurcay of our scaling algorithms/object samples etc.

Test of Photometric Pipelines (III)

Magnitude comparison of 28 simulated, pipeline processed `Skymaker` images vs. one *raw* `Skymaker` output frame:





`Skymaker` tests whether our pipeline processing (sky-background subtraction, selection of objects, image co-addition) has a significant influence on magnitude estimates. These studies helped us to optimise the selection of objects

The `Stuff` Program (version 1.11)

The user *needs* to specify:

- The angular extent of the simulation and basic telescope properties:

```
CATALOG_NAME     U38.list,...
IMAGE_WIDTH      2048   # (in pix)
IMAGE_HEIGHT     2048   # (in pix)
PIXEL_SIZE       0.238  # (in arcsec)
(COLLECT_AREA     2.8     # in m^2)
(GAIN             2.4     # (in e-/ADU))
```

- The observed passbands and the used magnitude system:

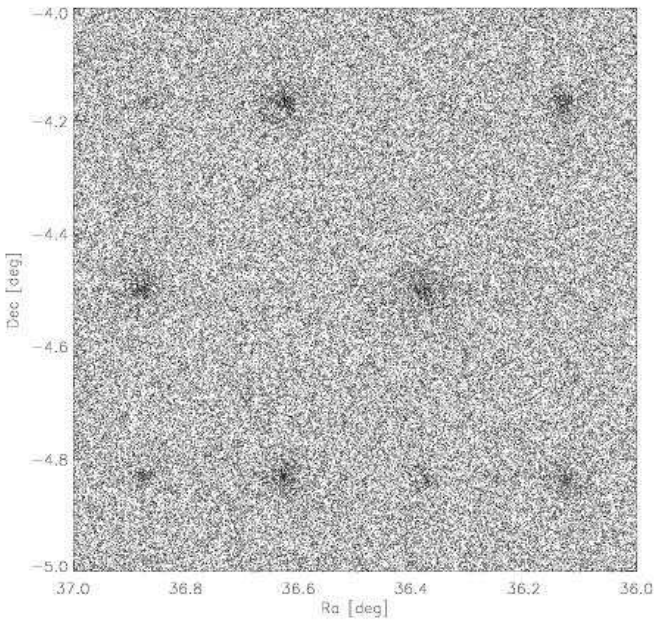
```
PASSBAND_OBS     wfi/WFI_U38,wfi/WFI_B,...
SED_CALIB        Vega   # Vega or AB
```

There are many other parameters which, in my opinion, do not need to be touched for most applications!

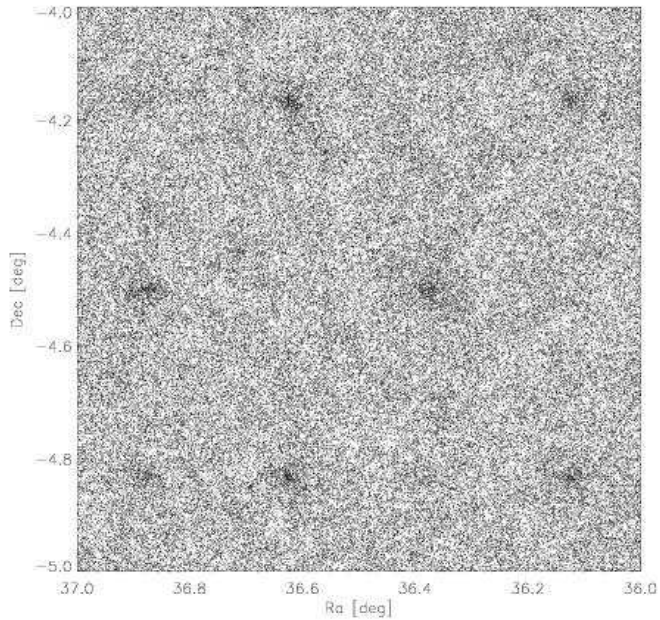
The `Stuff` Program: Galaxy Positions

Galaxies are distributed randomly in a *Poissonian way* in redshift slices from $0 < z < 20$ (no galaxy clustering!)

uniform galaxy distribution



clustered galaxy distribution



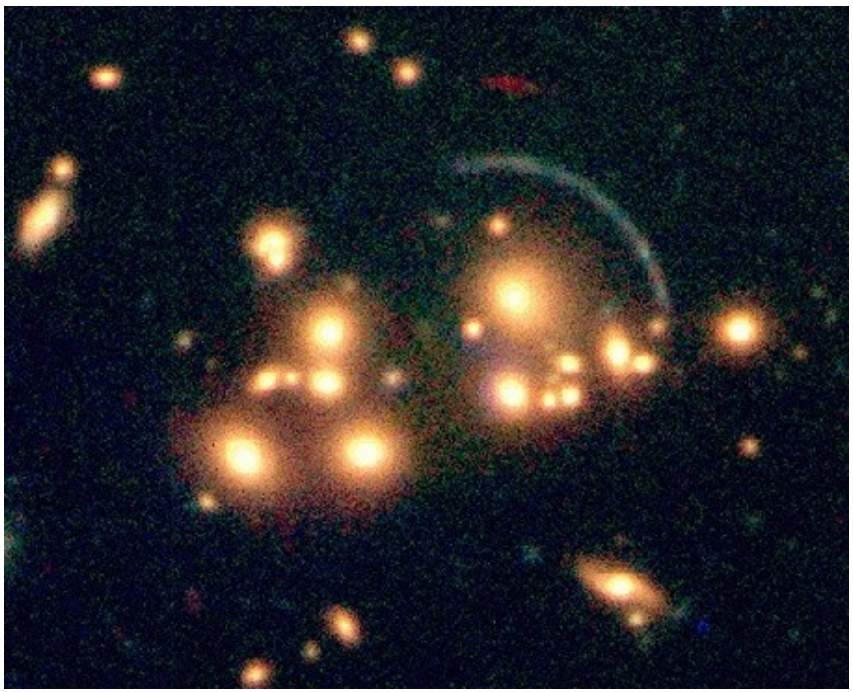
(Figures from Olsen et al. 2006)

`Stuff` produces a uniform galaxy distrbution; it should be *clustered* for applications such as investigating the efficiency of cluster search algorithms (see e.g. Soneira & Peebles 1978).

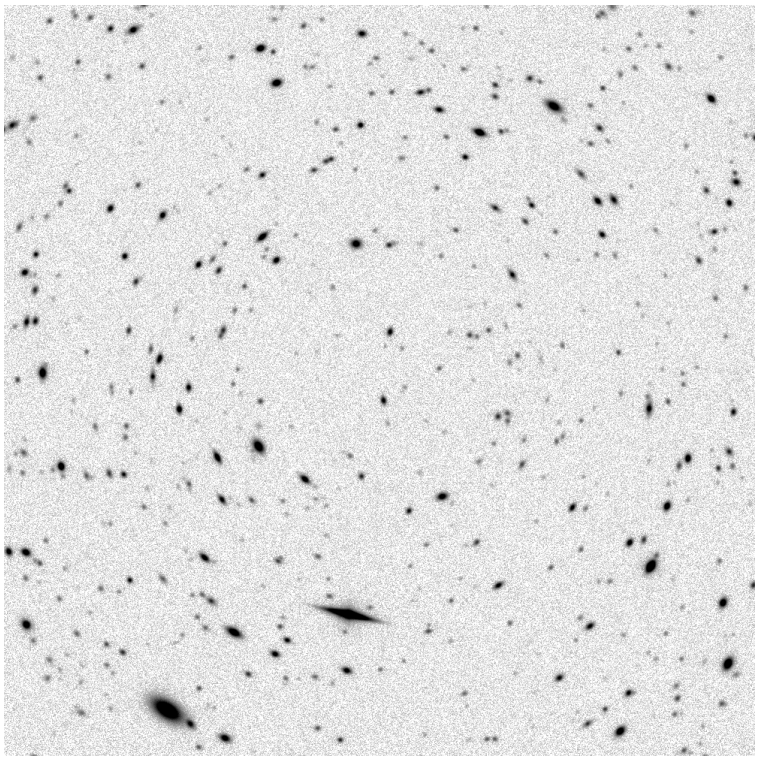
The `Stuff` Program: Galaxy Distributions

The *simple* redshift slice distribution from high to low redshifts does not allow to include strong lensing features. For this, ray tracing would be necessary.

Giant Arc in CL2244



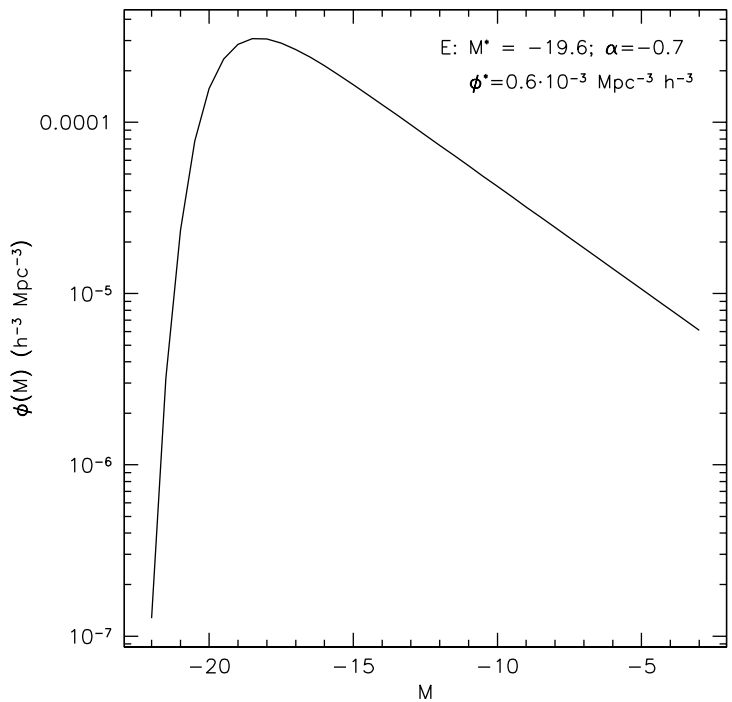
Giant 'Arcs' in `Skymaker`

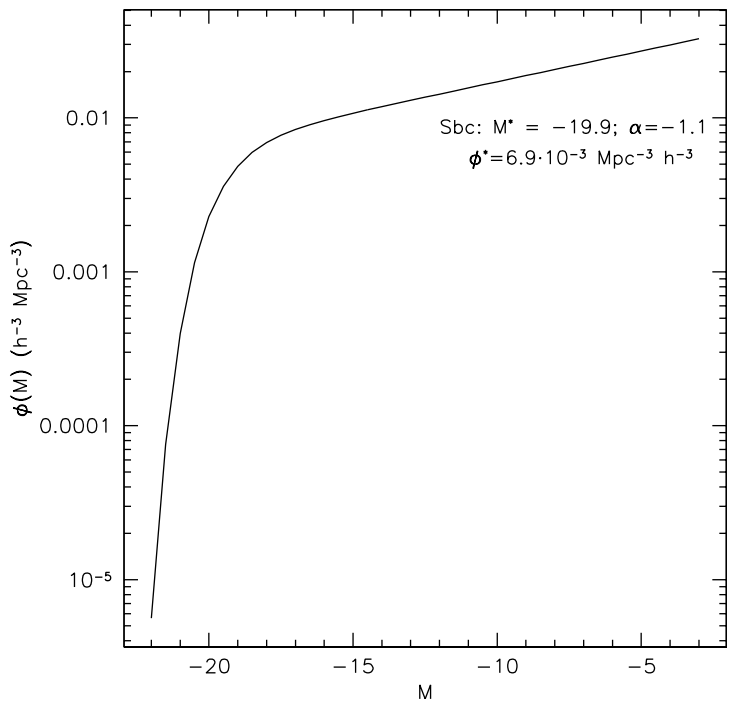


The `Stuff` Program: The Distribution of Galaxy Types

The number and absolute luminosity of galaxies is taken from a Schechter luminosity function in the *B*-band:

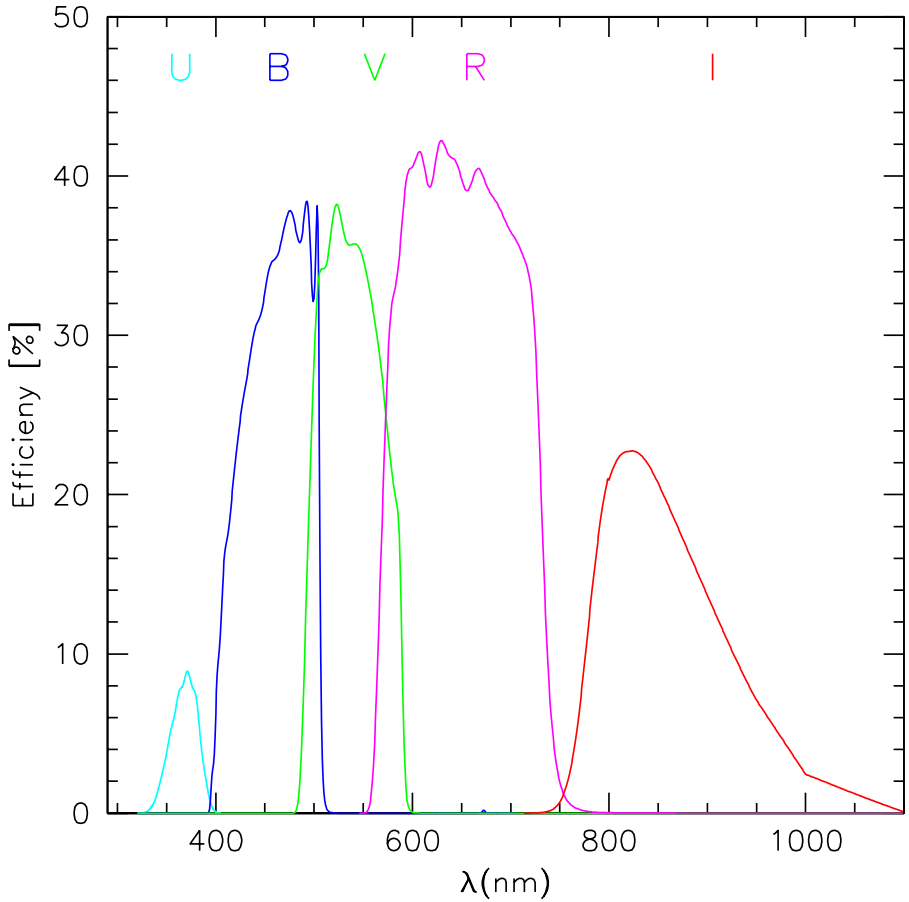
$$\phi(L)dL = \phi^* \left(\frac{L}{L*}\right)^{\alpha} \exp\left(-\left(\frac{L}{L*}\right)\right) d\left(\frac{L}{L*}\right)$$



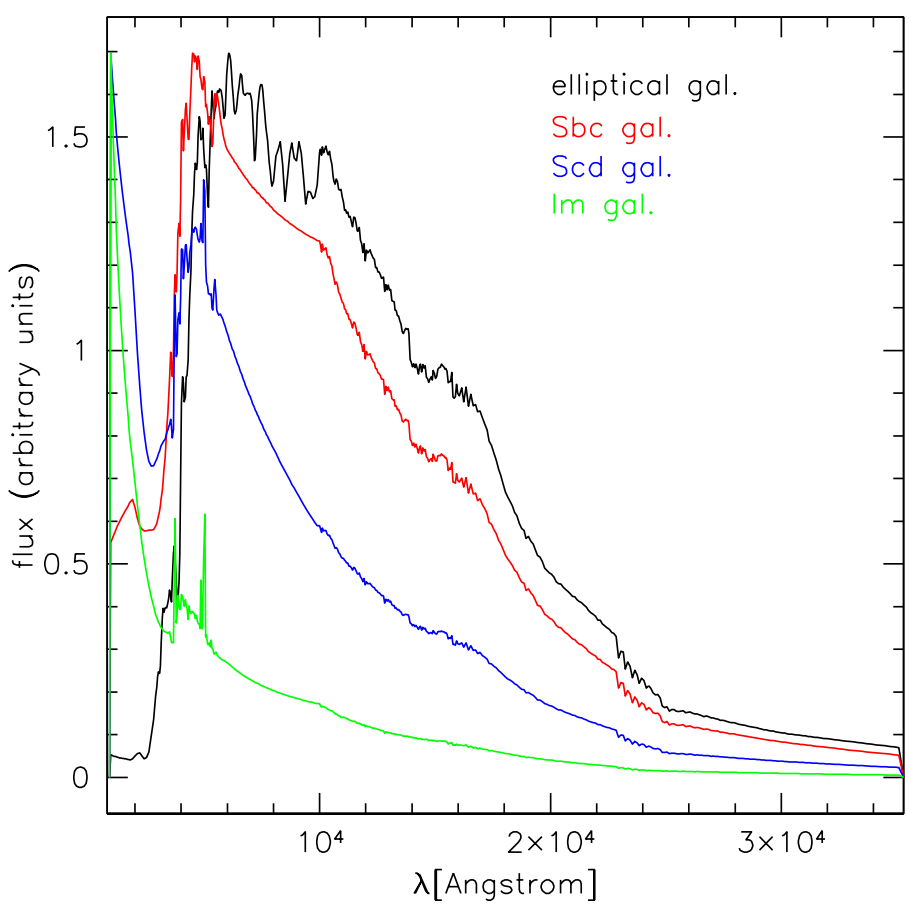


The `Stuff` Program: SEDs and Instrument Filter Curves

WFI filter curves



`Stuff` SEDs



Arbitrary filter curves and SEDs can be given to `Stuff`. As SEDs it uses the Coleman et al. (1980) templates.

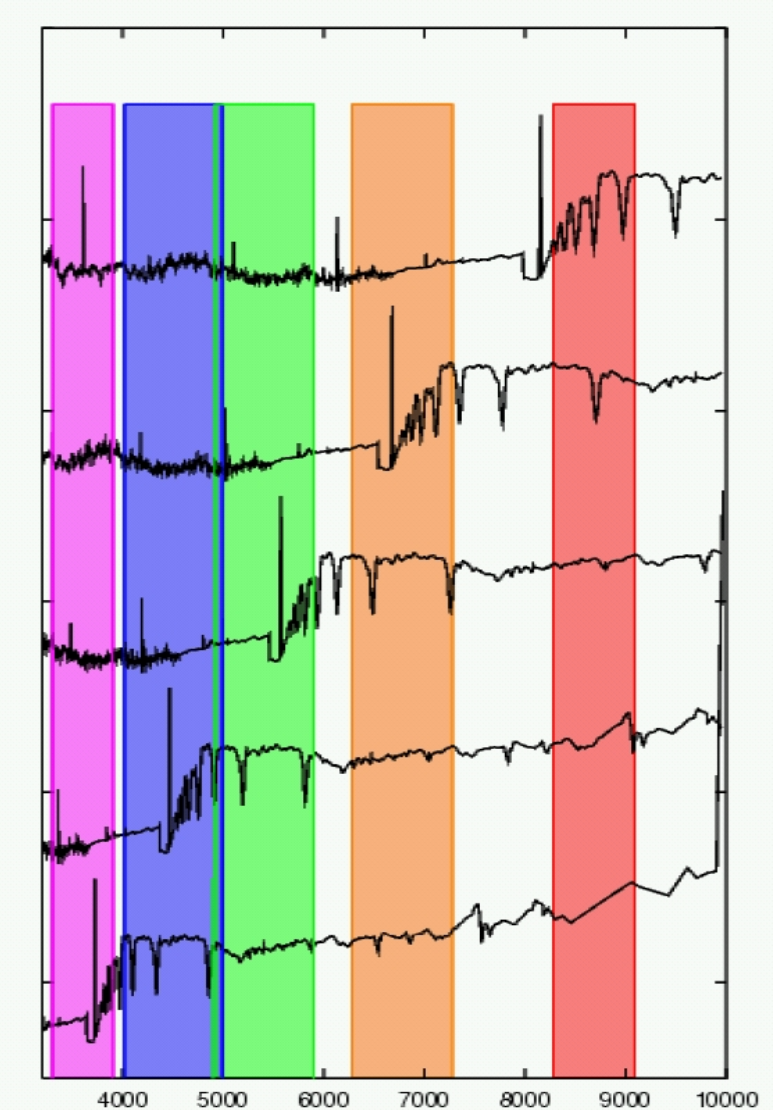
The `Stuff` Program: Photometry

Given is the total luminosity M_B in a *reference band*, here the blue. Together with the knowledge of the spectral energy distributions and the redshift of a galaxy the *observed* flux m in any passband can be calculated:

$$m = M_B + DM(z) + K(z),$$

with $DM(z)$ the distance modulus and $K(z)$ the *k-correction* (no extinction included in the formula!).

Redshifted Templates
(from Mellier 2006)



The Output `Stuff` Catalogue

`Stuff` can produce ASCII catalogues for an arbitrary number of observed filters at the same time (multi-colour catalogues):

```
200   611.634 1421.220   24.6608 ......   3.50661
200   717.635  -40.110   26.720  ......   3.47838
200   986.630  -50.237   25.2722 ......   2.95611
```

Important Columns for us (Stuff version 1.11!):

- two and three: pixel position in simulated image
- four: apparent magnitude
- seven/eight: bulge axis ratio and position angle
- ten/eleven: disk axis ratio and position angle
- twelve: galaxy redshift

Note that `Stuff` catalogues contain *only* galaxies. A modeling of stellar sources is currently not implemented in `Stuff` but this is probably added in the future.
Note that bulge and disks have, in general, different ellipticities (shear simulations)

The Skymaker program (I)

!! Many internals of this program are not yet clear to me !!

The Skymaker program takes the Stuff catalogues and creates FITS images. The user *needs to specify* (the absolute minimum):

- The extent of the simulation, basic telescope and exposure properties (needs to match parameters for Stuff!):

```
IMAGE_NAME      field.fits
IMAGE_SIZE      2000,2000
GAIN            2.40          # in (e-/ADU)
EXPOSURE_TIME   620.0         # (in s)
MAG_ZEROPOINT   26.0          # (in ADU/s)
PIXEL_SIZE      0.238         # (in arcsec)
SEEING_FWHM     0.7           # (in arcsec)
BACK_MAG        20.0          # (in mag/arcsec^2)
```

- Details on the stellar counts:

```
STARCOUNT_ZP     3e4       # stars /deg2 <= MAG_LIM
STARCOUNT_SLOPE  0.2       # (dexp/mag)
MAG_LIMITS       17.0,26.0 # magnitude range
```

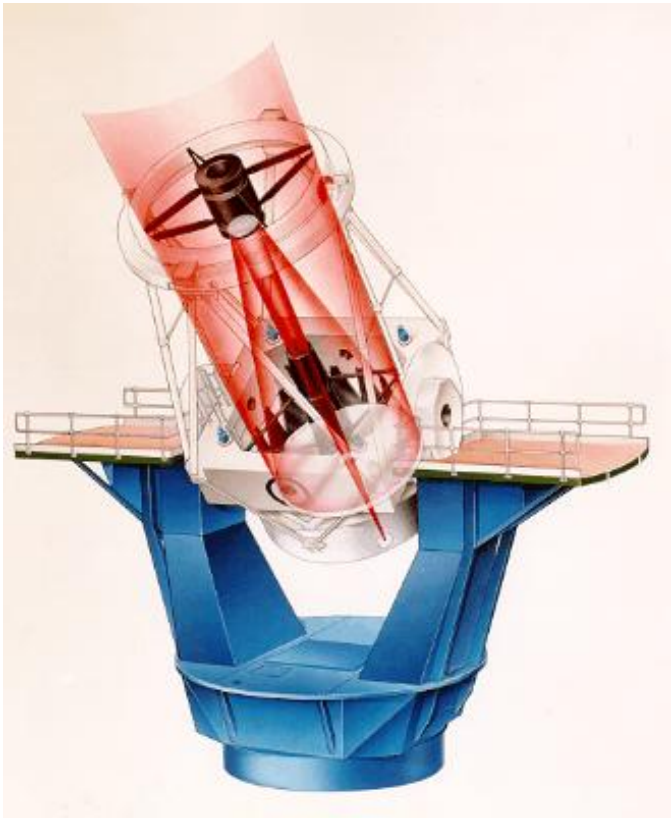
The Skymaker program (II)

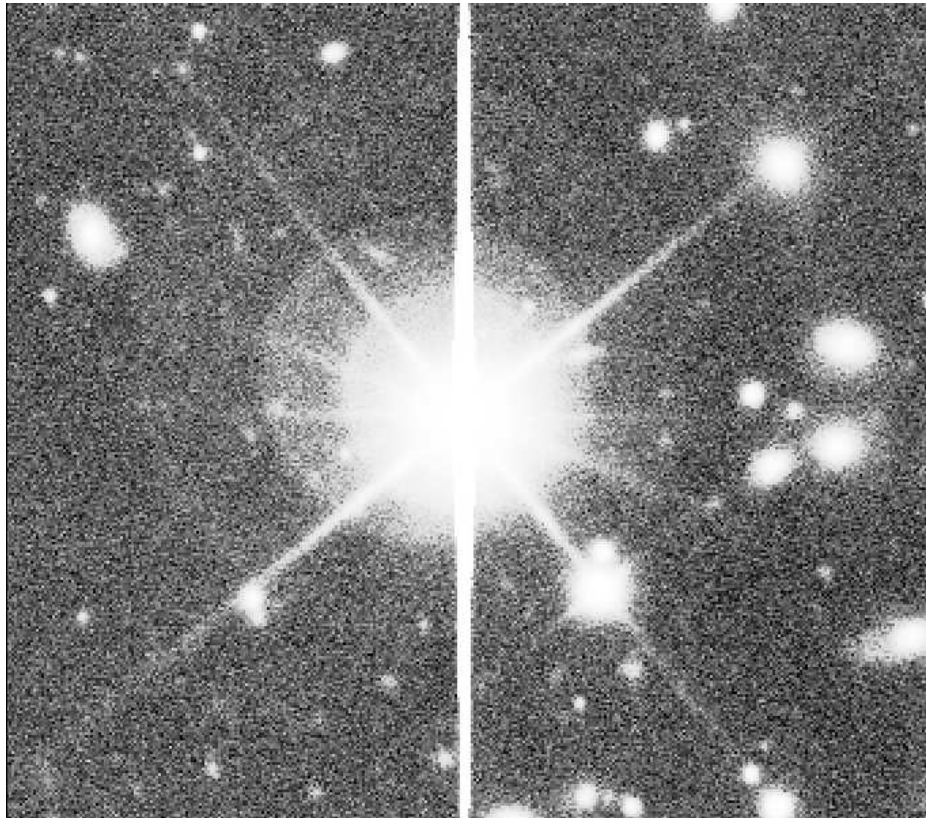
A simulated FITS image is created:

- The PSF is internally constructed taking into account: telescope aperture, atmospheric seeing, optical aberrations, telescope jittering
- *Stars* are distributed *randomly* with a magnitude distribution of a simple power law (no realistic colour information in case of multi-colour exposures); we can add stars to the Stuff catalogues ourselfs
- Galaxies are modeled as superposition of de Vaucouleurs and exponential disks, convolved with the PSF and put to the pixel grid
- Noise and blooming effects are added
- Result is an output catalogue (listing positions of galaxies and stars) and a FITS image with Skymaker configuration information in the FITS header

Skymaker is very careful about pixelisation effects (PSF sampling etc.)

PSF Realisation in `Skymaker`





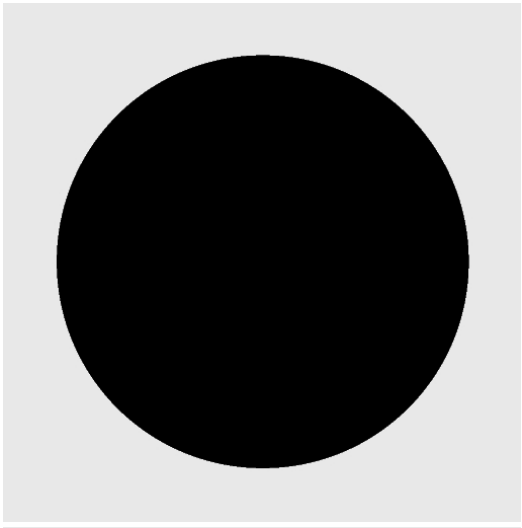
The intrinsic light distribution is smeared with the PSF P (Earth atmosphere, telescope optics):

$$I^{\mathrm{obs}}(x) = \int d^2y \, I^{\mathrm{intr}}(y) P(x-y)$$

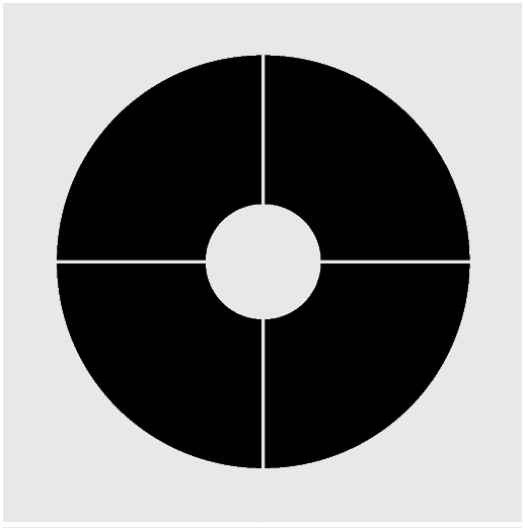
The Construction of Skymaker PSFs

Skymaker has very interesting check images!

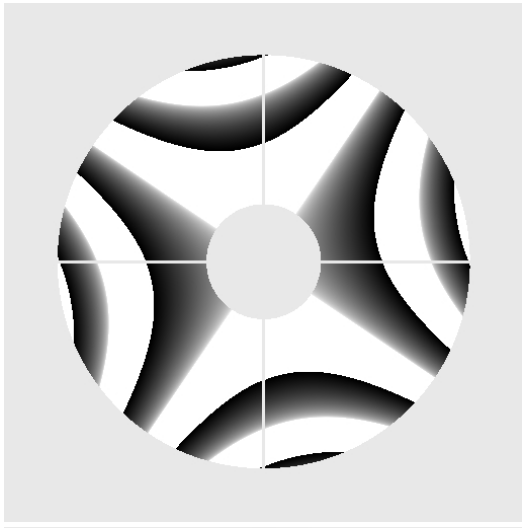
mirror aperture

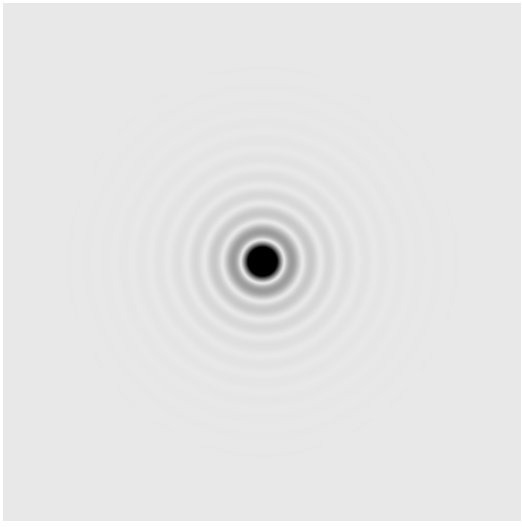


sec. mirror; spider arms

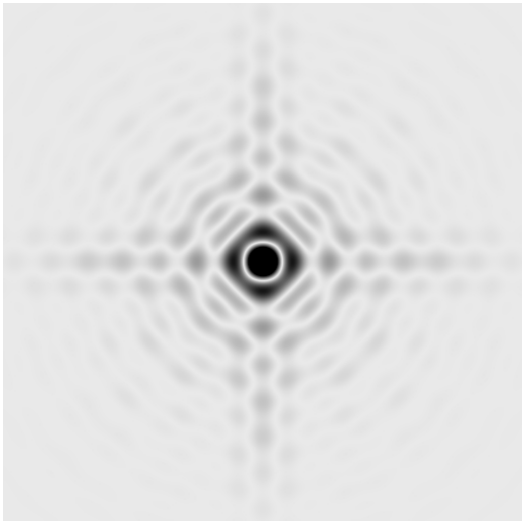


Astigmatism

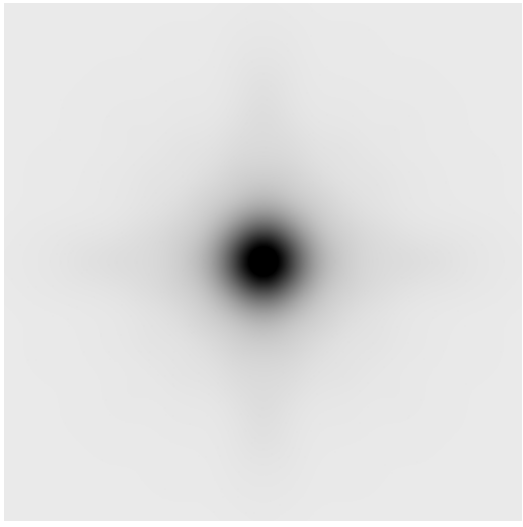




Airy pattern



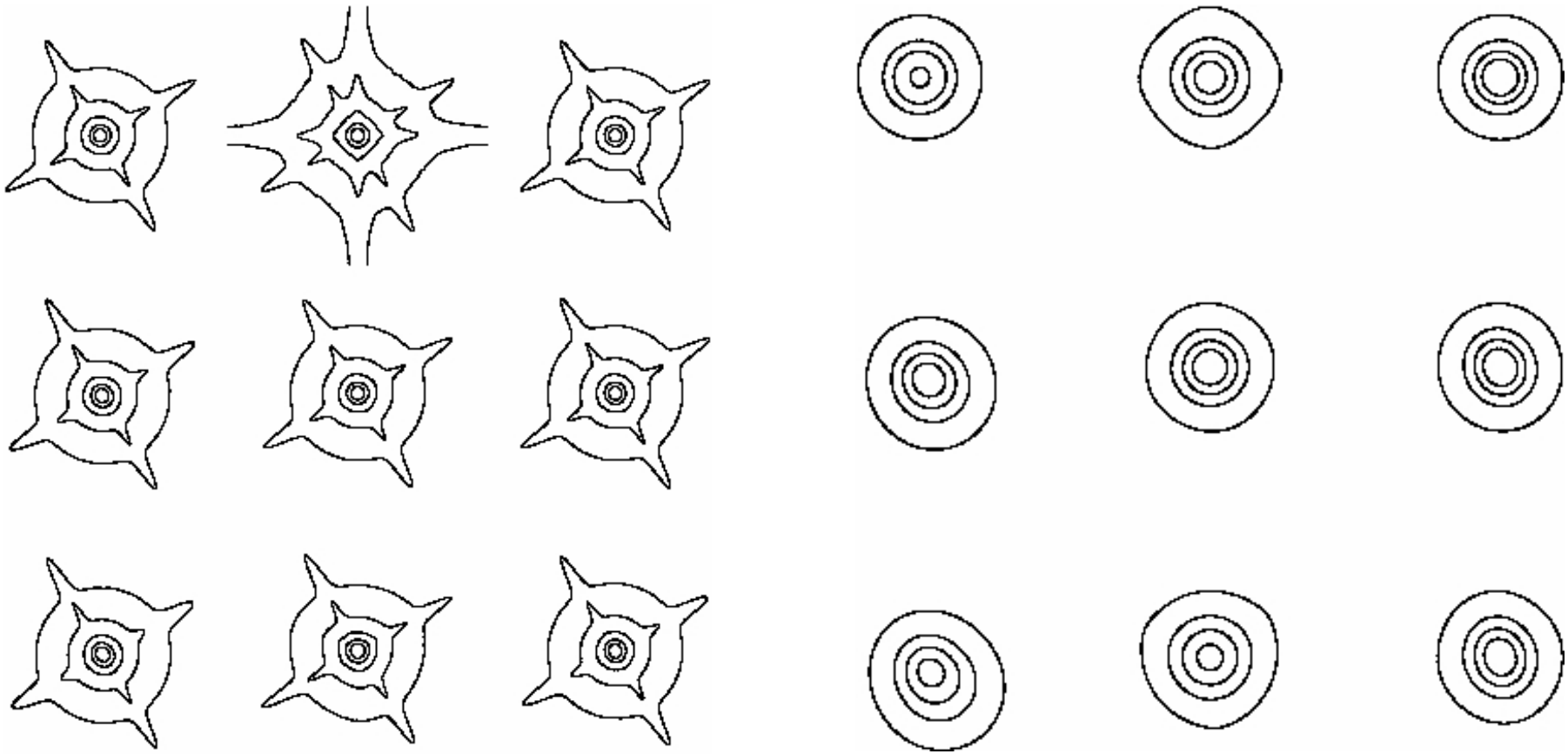
modified Airy



final PSF

Shape of Skymaker PSFs

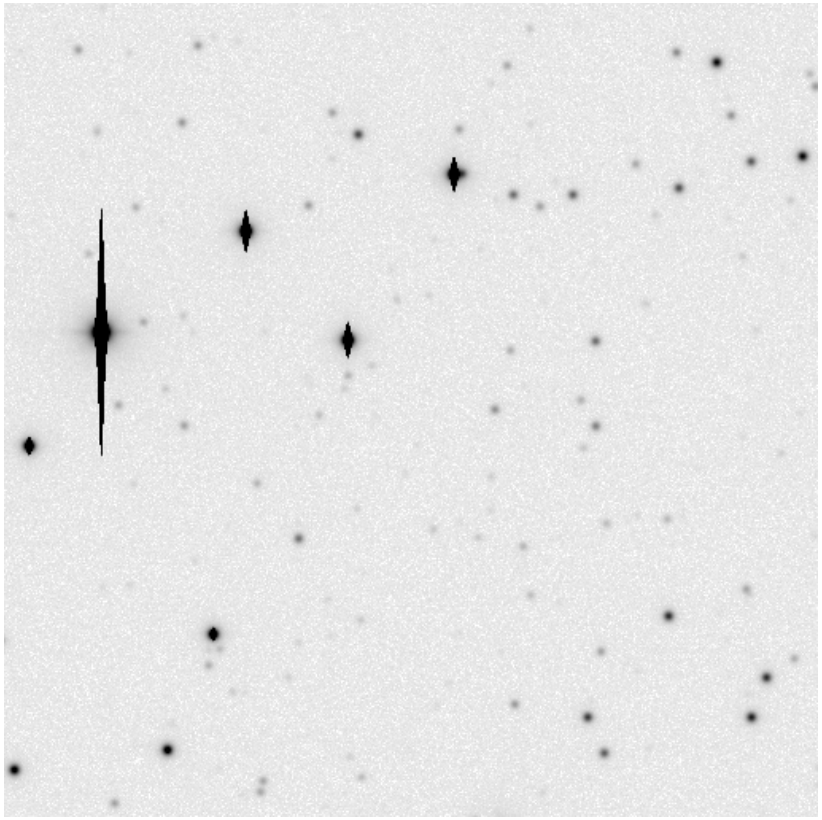
Contours for Skymaker PSFs with various optical aberrations (used for weak shear simulations)

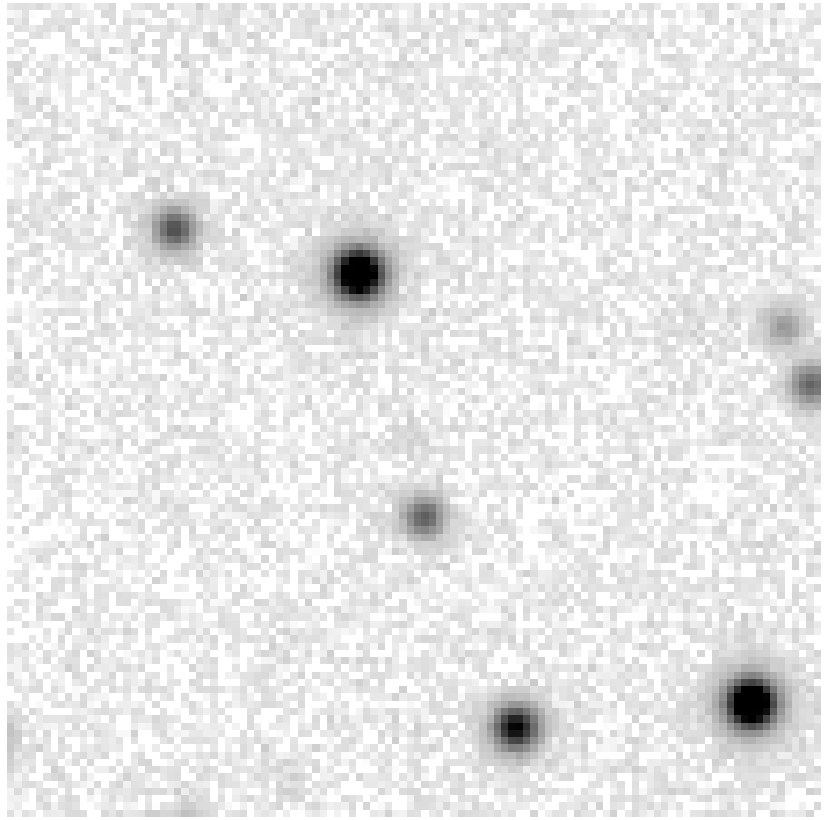


The cores of the PSFs contain more than 80% of the light!

Noise and Artefacts in `Skymaker`

Blooming effects occur if the number of electrons in a pixel exceeds the `WELL_CAPACITY`; sky noise is Poissonian





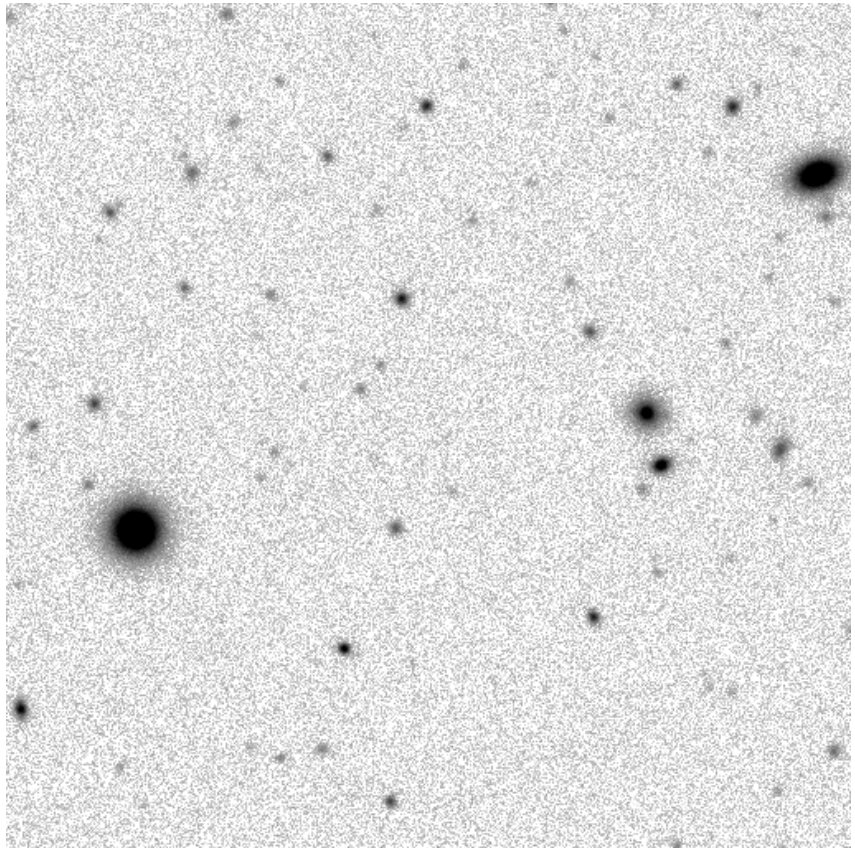
The level of noise is determined by the provided sky brightness (Typical values for CFHT in *dark time* (Unit is $mag/(''')^2$): u^*: 22.1; g': 22.0; r': 21.4; i': 20.4; z': 19.6)

The output `Skymaker` Image

FITS Header

```
NAXIS1   =                 2000
NAXIS2   =                 2000
.
.
GAIN     =            9600.000
WELLCAPA=    2.400000E+06
SATLEV   =              65535.0
RON      =                  4.8
EXPOTIME=                500.0
MAGZERO  =                 23.1
PIXSIZE  =                  0.2
.
.
```

Image Pixel Data



Two pitfalls with Skymaker: The *LONG* exposure

To simulate a *LONG* exposure it is *NOT* a good idea to just put a very high exposure time! All pixels would be saturated as in a real exposure.
Instead we simulate a long exposure as a sequence of *N* single frames with a small exposure time. To this the GAIN (and the WELL_CAPACITY) have to be multiplied by according factors:

1. An exposure of 500s (intrinsic GAIN is 1.62):
   GAIN: 1.62; EXPOSURE_TIME: 500 This mimics one exposure with an exposure time of 500s.
2. An exposure of 50000s (intrinsic GAIN is 1.62):
   GAIN: 162; EXPOSURE_TIME: 500
   This mimics an exposure of 50000s composed of 100 images a 500s.

The MAG_ZEROPOINT confusion

This is a general source for confusion, not only with Skymaker

The provided zeropoint MAG_ZEROPOINT for Skymaker is normalised for an exposure of 1 second, i.e. the unit of the zeropoint is ADU/s. However, the resulting Skymaker image is normalised to the exposure time of N seconds. Hence, to obtain correct magnitudes the zeropoint which needs to be given to SExtractor is:

$$\mathrm{MAGZP}_{\mathrm{SExtractor}} = \mathrm{MAG\_ZEROPOINT} + 2.5 \log(N)$$

Alternatively, you can normalise the Skymaker image to an exposure time of 1s and avoid recalculating the zeropoint:

1. Subtract the Sky-background
2. Divide the pixel values by the exposure time

All resulting co-added images from the THELI pipeline have the 1s normalisation and provided zeropints can directly be used.

Todays practical session

I give you a script which uses `Stuff` and `Skymaker` to mimic our D1 i'-band observation.

- Get familiar with the syntax of the programs
- Create a simulated multi-colour observation mimicing our D1 data in the five bands - You will need this tomorrow!
- Apply a constant gravitational shear to the `Stuff` galaxies prior to simulating an observation with `Skymaker`. You will use these data for the KSB practicals in the afternoon.