Multicolour Photometry
-
IPM School and Workshop on Weak Lensing and Photo-z Techniques

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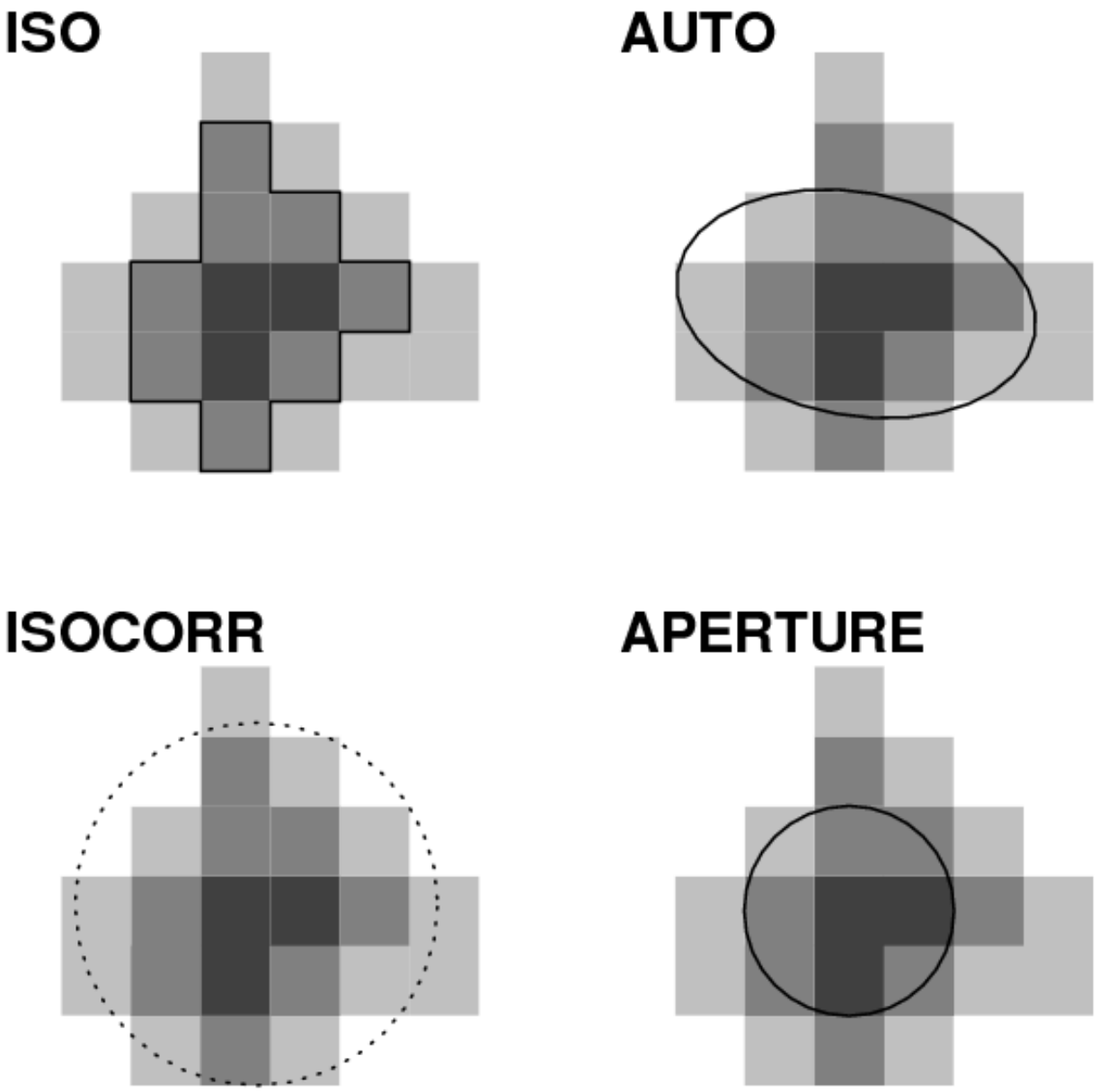
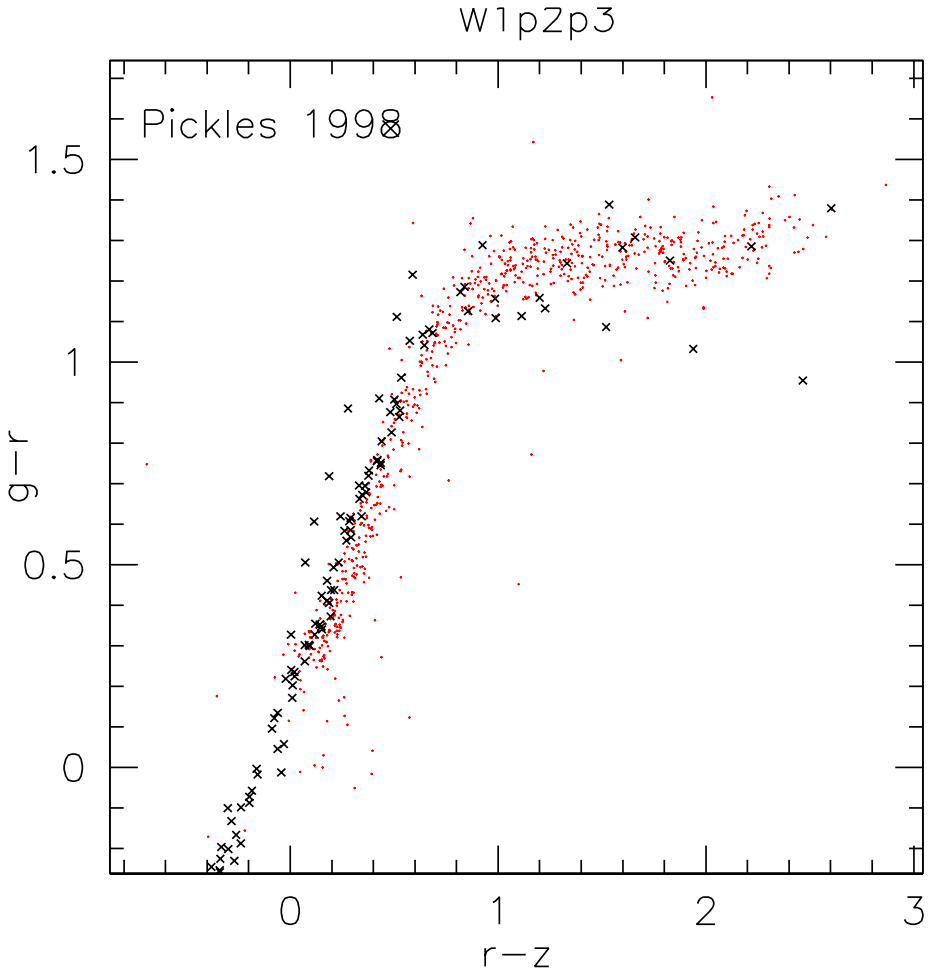
Outline

Different Magnitudes



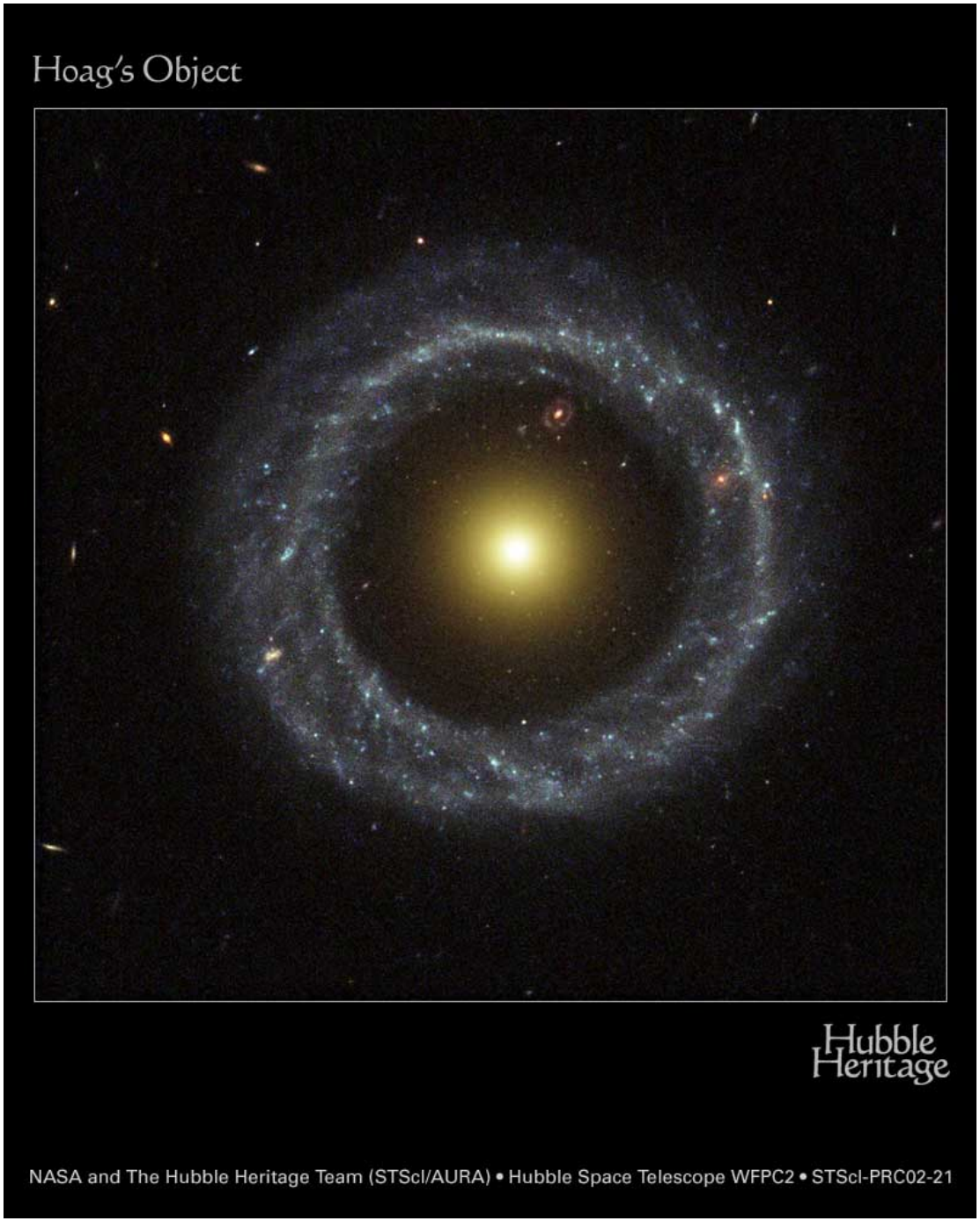
Quality Control



Introduction

Multicolour photometry

- Tricky business.
- Especially hard from the ground.
  - Blurring by the athmosphere.
  - Varying extinction.
- Here we focus on photometric redshifts.
- Not necessarily interested in total magnitudes.
- Going from calibrated images to a usable catalogue.


Hoag's Object
Hubble Heritage
NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC02-21

Introduction

Multicolour photometry

- Measure the flux in the same **physical** aperture.
- Account for PSF effects.
- Estimate the background correctly.
- Know your limits accurately.

PSF Homogenization

Why homogenise the PSF

Images in different bands are usually taken in different seeing conditions.
$\Rightarrow$ The same galaxy will have different sizes in the different bands.

How to homogenise the PSF

- Poor man's approach: Take large apertures so that PSF doesn't matter.
- Classical approach: Degrade all images to the PSF of the image with the largest PSF.
- More advanced techniques:
  - Model-fitting
  - Shapelet-based (GaaP)

The Classical Approach

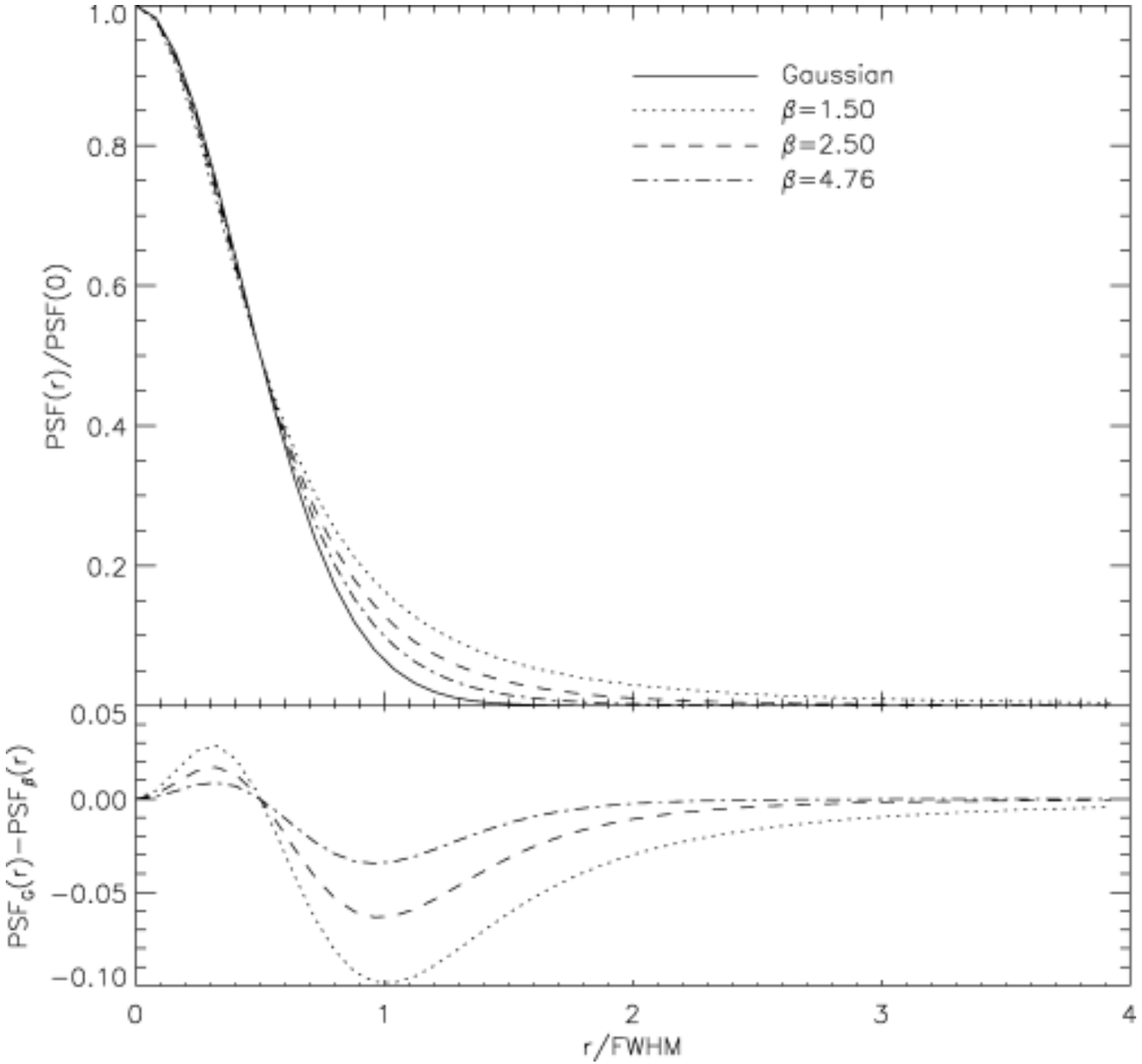
Assumption

In the following we assume that the PSF is Gaussian. PSF and seeing will be used synonymously.

Steps

1. Measure the seeing.
2. Identify the image with the worst seeing.
3. Calculate filter functions that will filter one particular image to the seeing of the image with the worst seeing.
4. Filter all images but the worst one.
5. Measure the seeing again.

Moffat Profile



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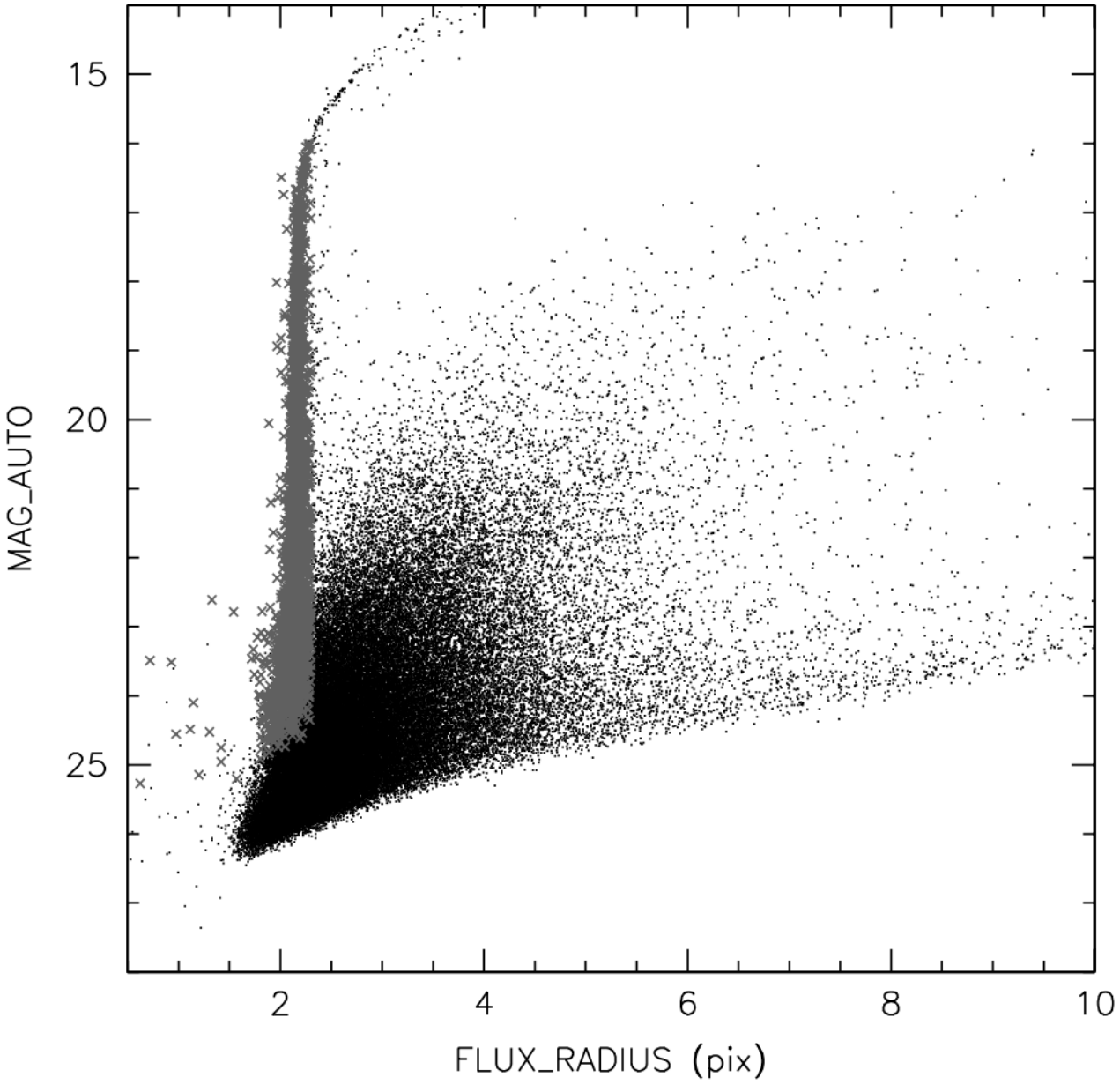
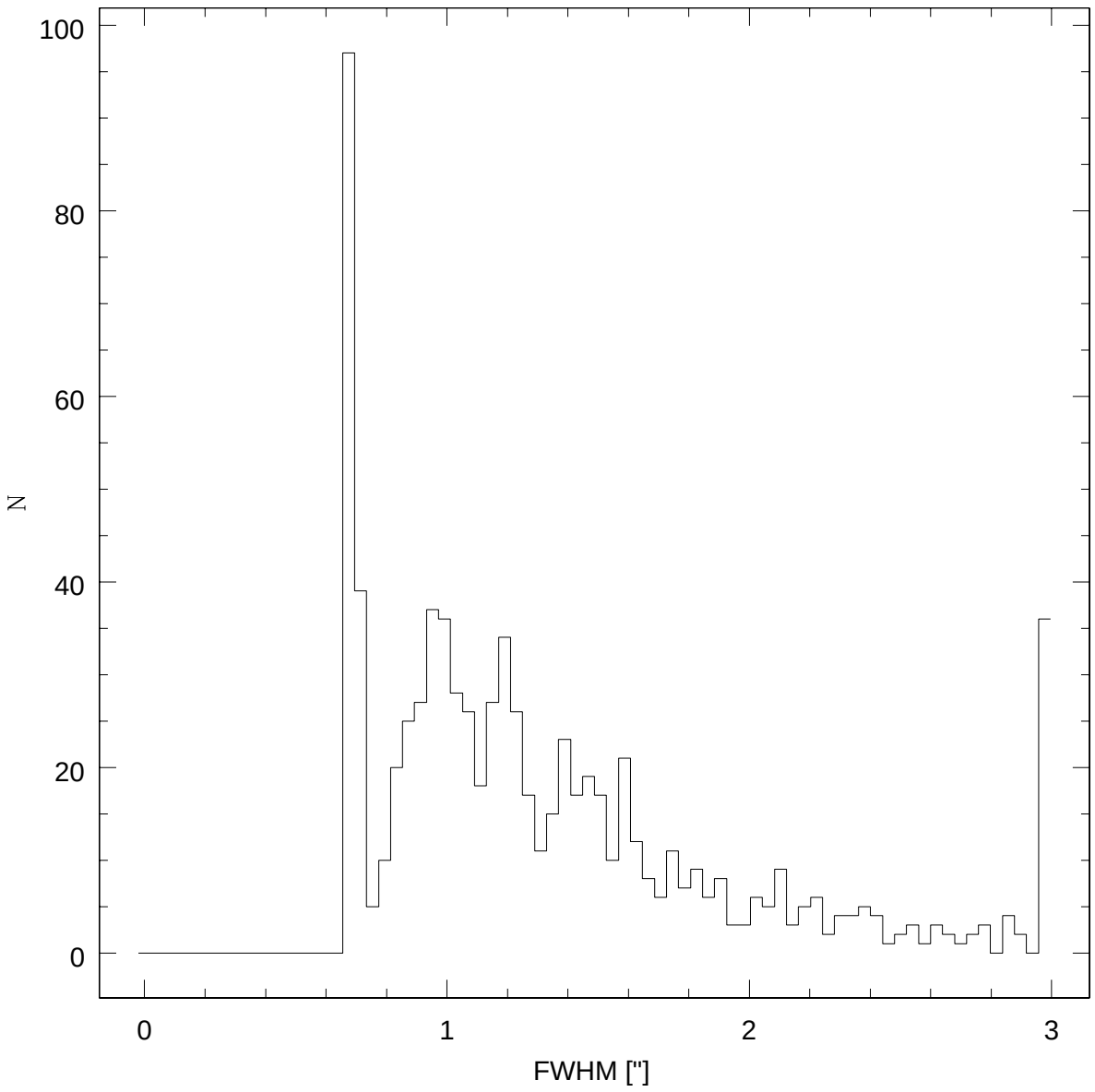
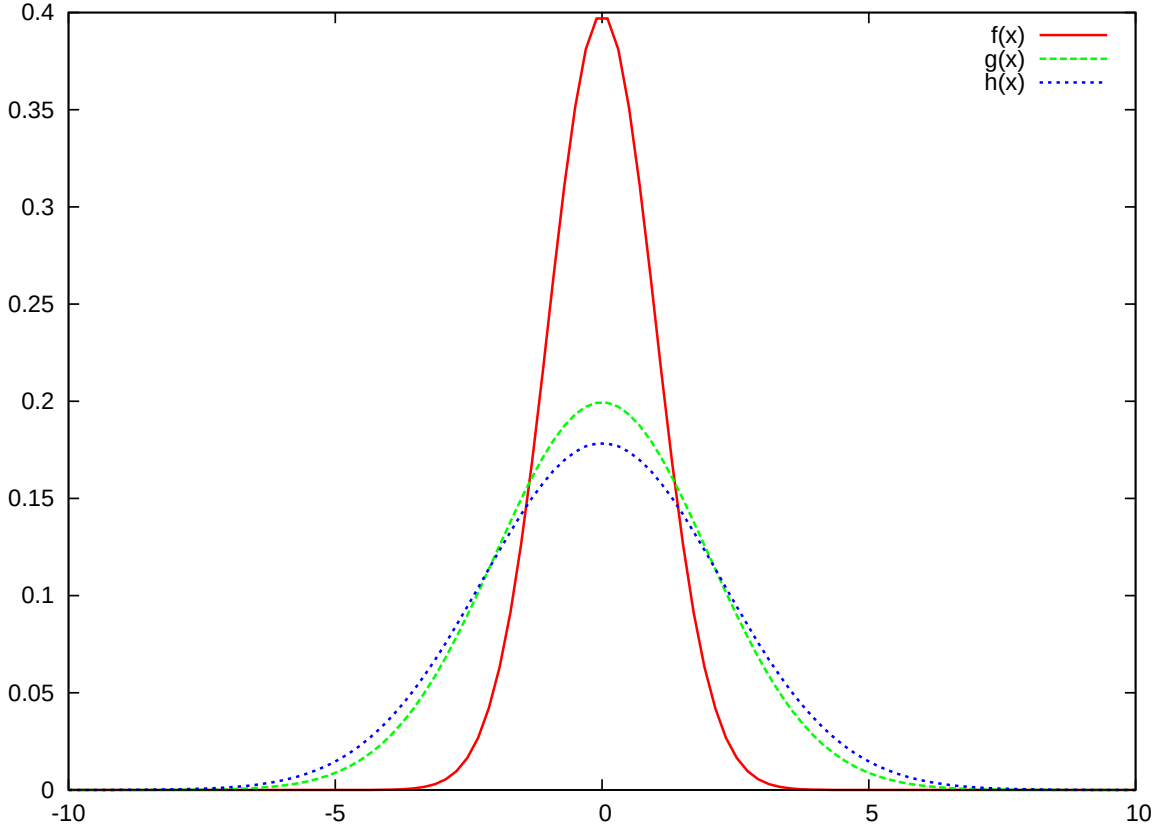
Seeing Measurement



Seeing Measurement



Convolution of Gaussians



$f(x)$, $g(x)$: Gauss functions with $\sigma_f = 1$ and $\sigma_g = 2$.

$$(f * g)(x) = \int_{-\infty}^{\infty} f(t)g(x-t)\mathrm{d}t = h(x)\,,$$

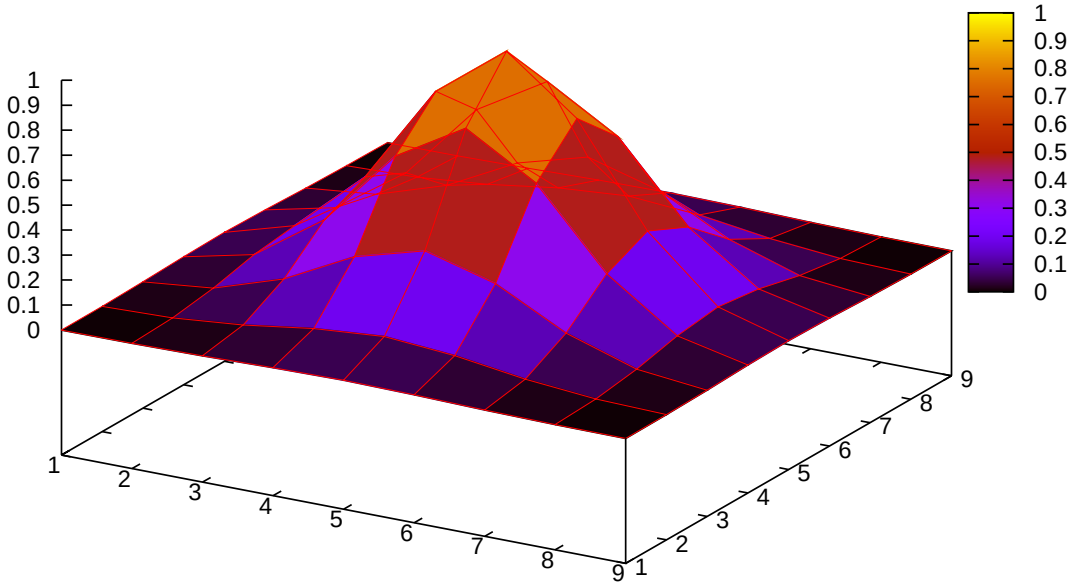
with $h(x)$ being again a Gauss function and $\sigma_h = \sqrt{\sigma_f^2 + \sigma_g^2} = \sqrt{5}$

SExtractor with a filter file

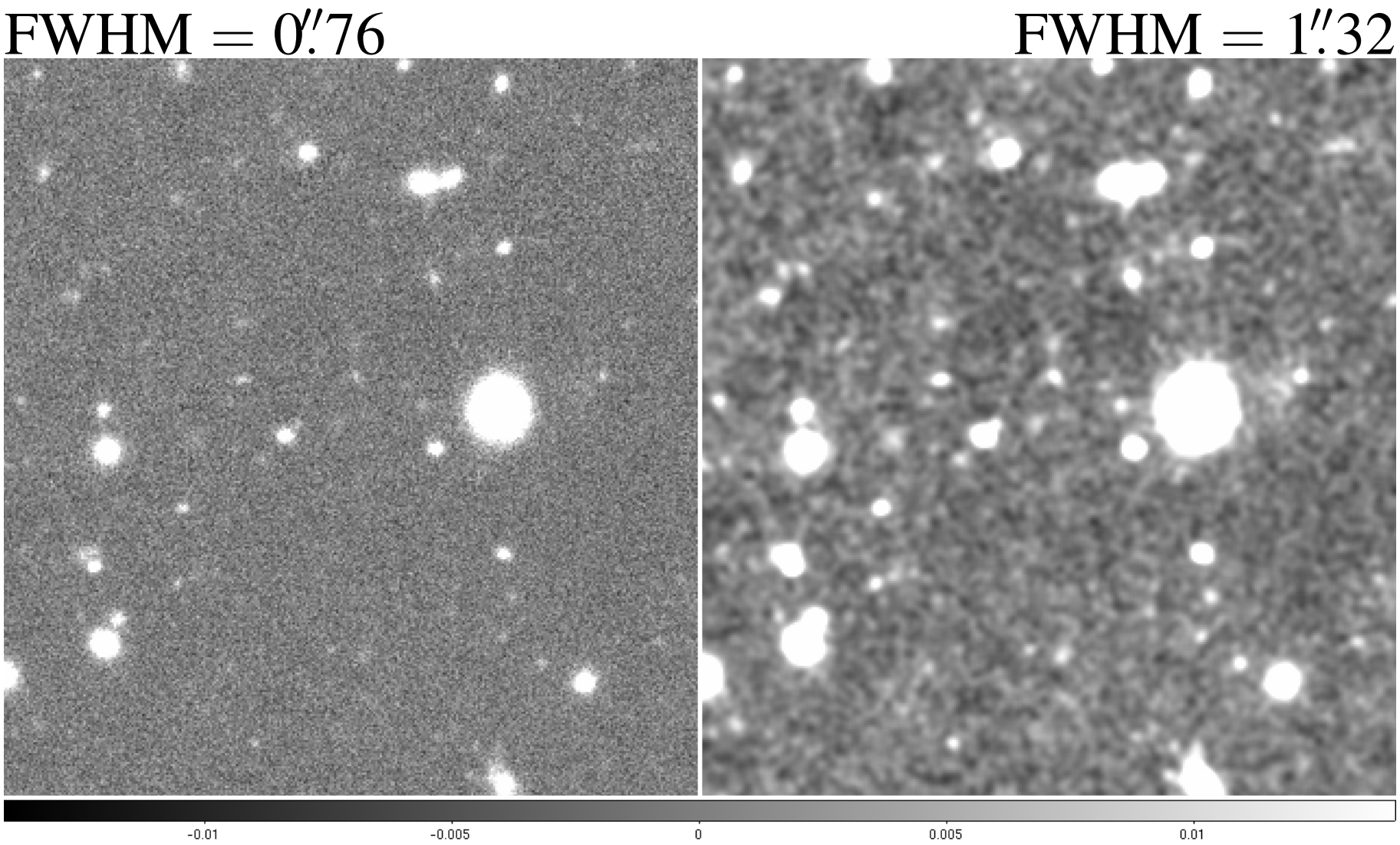
```
sex image.fits -FILTER Y \
               -FILTER_NAME filter.asc \
               -CHECKIMAGE_TYPE FILTERED \
               -CHECKIMAGE_NAME image.filt.fits
```

filter.asc

```
CONV NORM
0.000281 0.001665 0.005934 0.012712 0.016386 0.012712 0.005934 0.001665 0.000281
0.001665 0.009884 0.035224 0.075459 0.097265 0.075459 0.035224 0.009884 0.001665
0.005934 0.035224 0.125522 0.268902 0.346610 0.268902 0.125522 0.035224 0.005934
0.012712 0.075459 0.268902 0.576061 0.742532 0.576061 0.268902 0.075459 0.012712
0.016386 0.097265 0.346610 0.742532 0.957110 0.742532 0.346610 0.097265 0.016386
0.012712 0.075459 0.268902 0.576061 0.742532 0.576061 0.268902 0.075459 0.012712
0.005934 0.035224 0.125522 0.268902 0.346610 0.268902 0.125522 0.035224 0.005934
0.001665 0.009884 0.035224 0.075459 0.097265 0.075459 0.035224 0.009884 0.001665
0.000281 0.001665 0.005934 0.012712 0.016386 0.012712 0.005934 0.001665 0.000281
```



Result - before and after



SExtractor in dual-image mode

```
sex detection.fits measurement.fits
```

`detection.fits`:
Image on which the sources are detected. This should be your deepest **unconvolved** image. All positional and shape information are taken from this image. Also the apertures, isophotes, etc. are defined on this image.

`measurement.fits`:
Convolved image on which the fluxes and their errors are measured in the apertures/isophotes defined on `detection.fits`. Nothing else is done on this image.

SExtractor in dual-image mode

Run SExtractor N times where N is the number of bands.

Also run

```
sex detection.fits detection.fits
```

to get a catalogue with total magnitudes in your detection band. The other magnitudes measured on the **convolved** image are not total magnitudes since flux is missing. The convolution has spread this flux to a larger area. Remember: The apertures were defined on the **unconvolved** image where objects tend to be smaller. Still, for colours these magnitudes measured on the **convolved** images are fine.
To get total magnitudes in a different band (say Y) than your detection band (say X):

$$Y_{\text{total}} = X_{\text{total}} - X_{\text{conv.}} + Y_{\text{conv}} \,.$$

SExtractor in dual-image mode

Caution

- Convolution changes the noise properties.
- Unrealistic faint magnitudes are sometimes put out.
- Assumption of Gaussian PSF breaks down if the FWHM are very different.
- Always keep track of what is measured on which image.
- Don't mistake the magnitudes measured on the convolved images for total magnitudes.
- Remember that you used stars for PSF equalisation.

Limiting Magnitudes

A non-detection can constrain the SED if you know the upper flux limit set by this non-detection.

Know your limits...

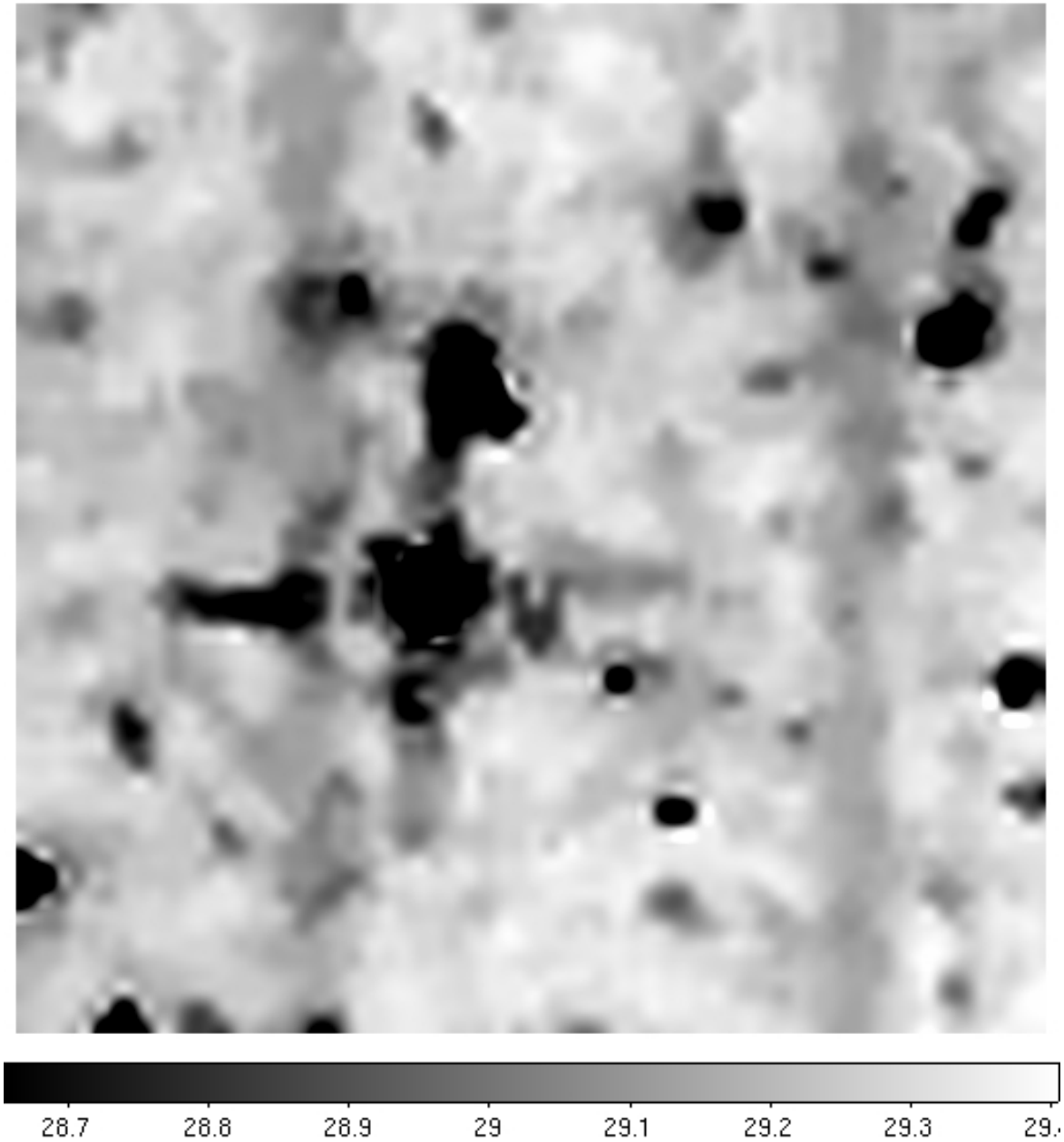
- Limiting magnitudes are given in multiple different ways:
  - How many sigmas?
    $\mathrm{mag}_{\text{lim; 10-}\sigma} = \mathrm{mag}_{\text{lim; 5-}\sigma} - 0.75 = \mathrm{mag}_{\text{lim; 3-}\sigma} - 1.3 = \mathrm{mag}_{\text{lim; 1-}\sigma} - 2.5$
  - In which aperture?
    The limiting magnitude scales with $-2.5 \log \sqrt{A}$, where A is the area of the aperture.
    $\mathrm{mag}_{\text{lim; 1''}} = \mathrm{mag}_{\text{lim; 2''}} + 0.75$
- Rule of thumb:
  $m_{\mathrm{lim,X}} - m_{\mathrm{lim,Y}} = -2.5 \log \left[\left(\frac{\mathrm{FWHM_X}}{\mathrm{FWHM_Y}} \right) \sqrt{\frac{t_{\mathrm{exp,Y}}}{t_{\mathrm{exp,X}}}} \left(\frac{D_{\mathrm{Y}}}{D_{\mathrm{X}}} \right) \right]$
- Limiting magnitudes can change as a function of position.

SExtractor RMS CHECKIMAGE

```
sex image.fits -CHECKIMAGE_TYPE RMS \
               -CHECKIMAGE_NAME image.rms.fits

ic 'FWHM/pix_scale*sqrt(pi) %1 * log -1.0857 *\
    ZP +' image.rms.fits\
  > image.maglim.fits
```

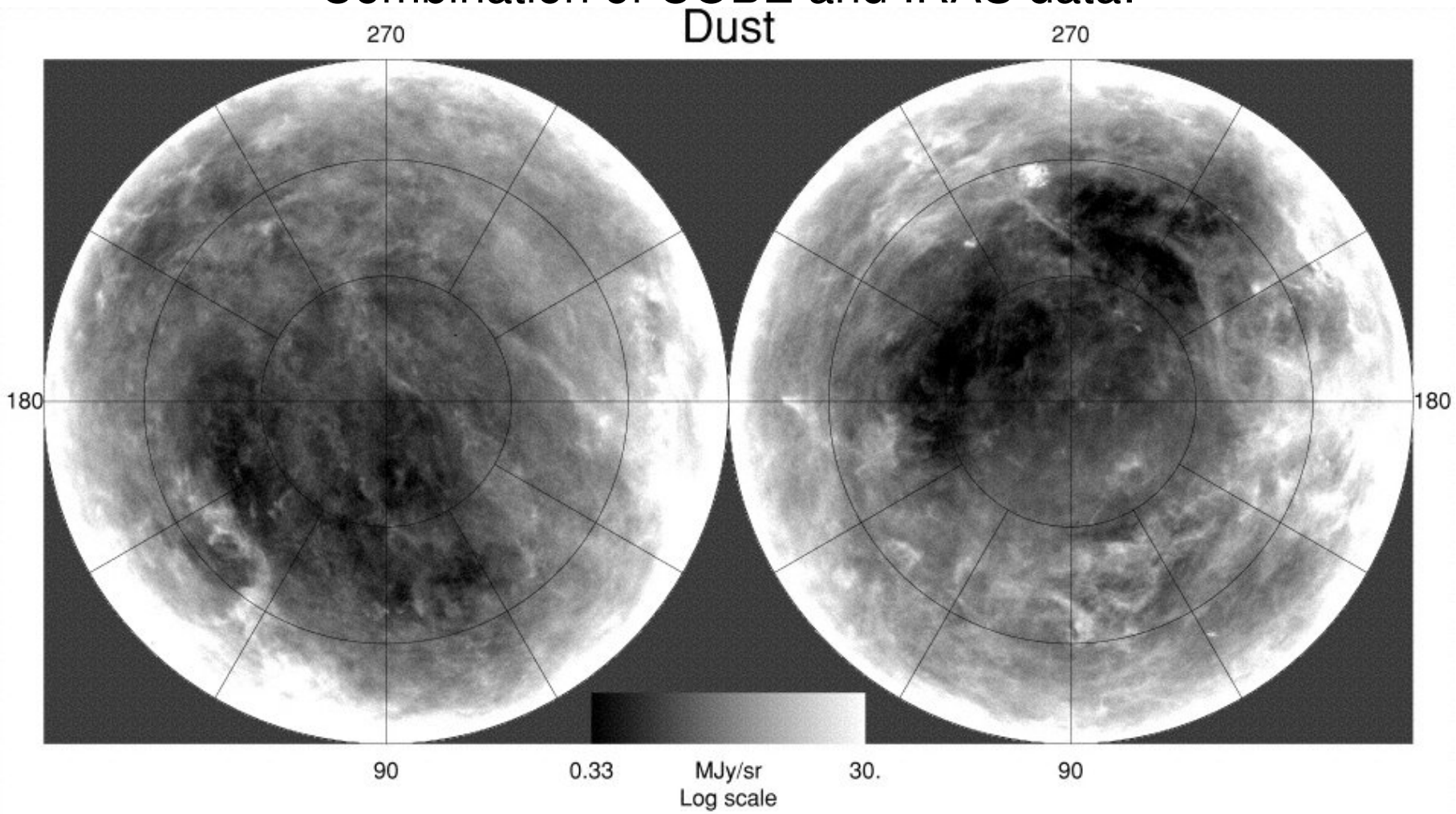
image.maglim.fits



Galactic Extinction

Schlegel Maps

Combination of COBE and IRAS data:



4903 citations!

Schlegel Maps

TABLE 6

RELATIVE EXTINCTION FOR SELECTED BANDPASSES

Filter	λ_{eff} (Å)	$A/A(V)$	$A/E(B-V)$	Filter	λ_{eff} Å	$A/A(V)$	$A/E(B-V)$
Landolt U	3372	1.664	5.434	Strömgren u	3502	1.602	5.231
Landolt B	4404	1.321	4.315	Strömgren b	4676	1.240	4.049
Landolt V	5428	1.015	3.315	Stromgren v	4127	1.394	4.552
Landolt R	6509	0.819	2.673	Strömgren β	4861	1.182	3.858
Landolt I	8090	0.594	1.940	Strömgren y	5479	1.004	3.277
CTIO U	3683	1.521	4.968	Sloan u'	3546	1.579	5.155
CTIO B	4393	1.324	4.325	Sloan g'	4925	1.161	3.793
CTIO V	5519	0.992	3.240	Sloan r'	6335	0.843	2.751
CTIO R	6602	0.807	2.634	Sloan i'	7799	0.639	2.086
CTIO I	8046	0.601	1.962	Sloan z'	9294	0.453	1.479
UKIRT J	12660	0.276	0.902	WFPC2 F300W	3047	1.791	5.849
UKIRT H	16732	0.176	0.576	WFPC2 F450W	4711	1.229	4.015
UKIRT K	22152	0.112	0.367	WFPC2 F555W	5498	0.996	3.252
UKIRT L'	38079	0.047	0.153	WFPC2 F606W	6042	0.885	2.889
Gunn g	5244	1.065	3.476	WFPC2 F702W	7068	0.746	2.435
Gunn r	6707	0.793	2.590	WFPC2 F814W	8066	0.597	1.948
Gunn i	7985	0.610	1.991	DSS-II g	4814	1.197	3.907
Gunn z	9055	0.472	1.540	DSS-II r	6571	0.811	2.649
Spinrad R_S	6993	0.755	2.467	DSS-II i	8183	0.580	1.893
APM b_J	4690	1.236	4.035				

NOTE.—Magnitudes of extinction evaluated in different passbands using the $R_V = 3.1$ extinction laws of Cardelli et al. 1989 and O'Donnell 1994. The final column normalizes the extinction to photoelectric measurements of $E(B-V)$.

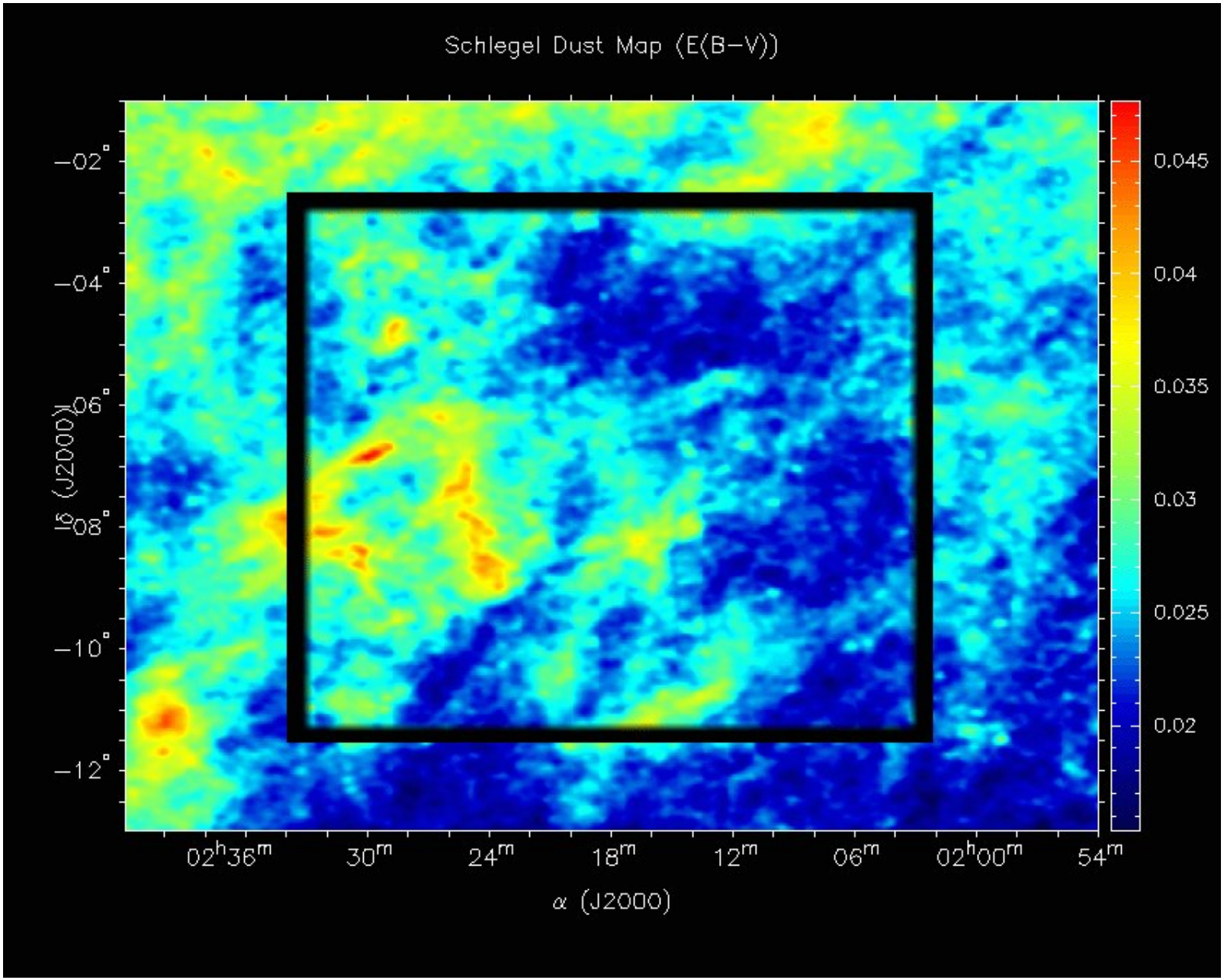
Correction for Galactic Extinction

What to do?

- Convert equatorial coordinates to galactic coordinates.
- Look up the $E(B-V)$ for that galactic position.
- Look up the conversion factor for your filter.
- Correct the magnitudes of extragalactic objects before running a photo-z code.
- Don't correct stars. They may be in the foreground.

In the CFHTLS-Wide you may bias your $u-z$ colour by $\sim 0.3\mathrm{mag}$ if you don't correct for extinction!

CFHTLS-W1 field



Alternative Approaches

Other options

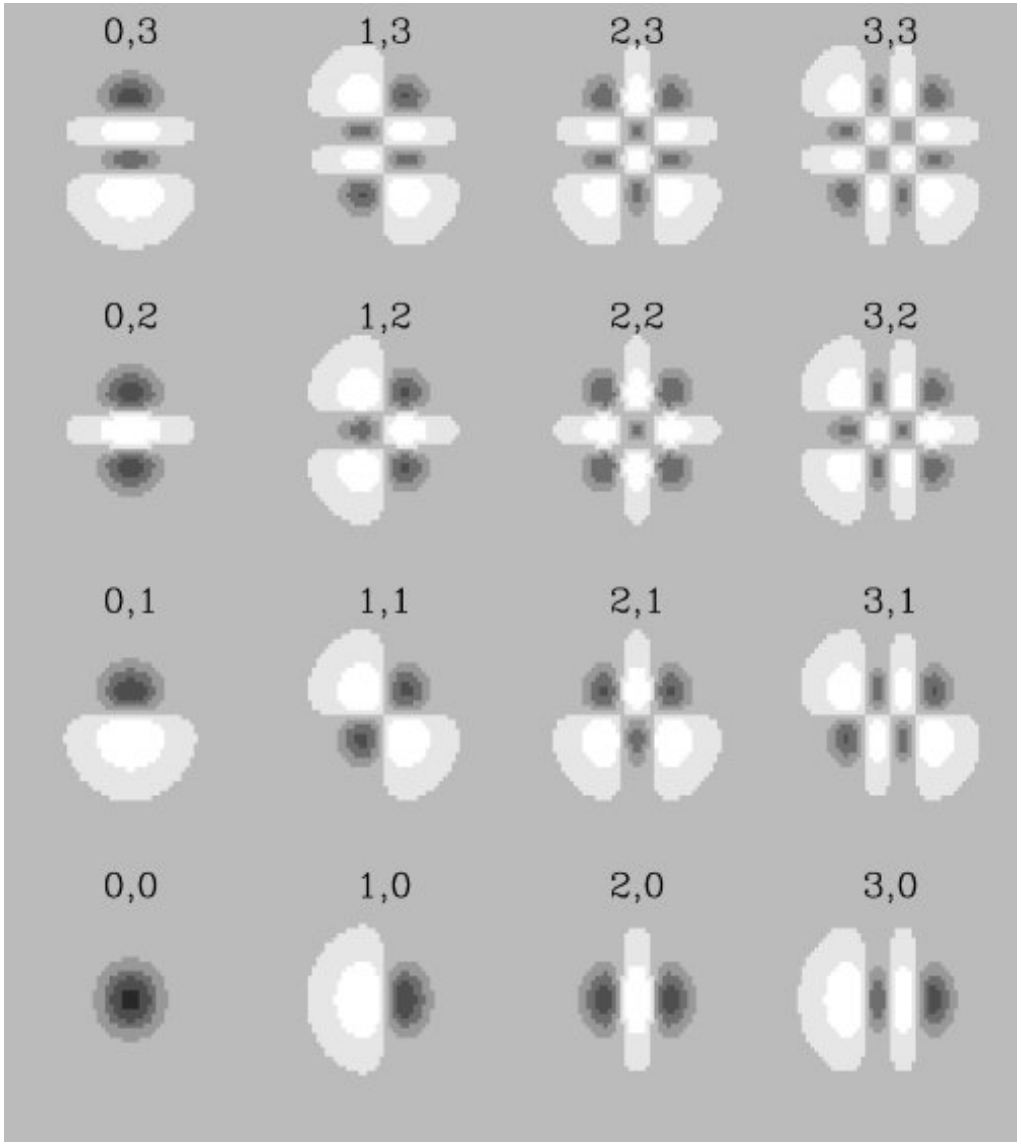
- Fitting of a physically motivated model convolved with a PSF model. Done in the SDSS.
- GaaP: Decomposition of the PSF and the galaxy images into shapelets (see lecture by K. Kuijken).

Model Fitting

How it's done:

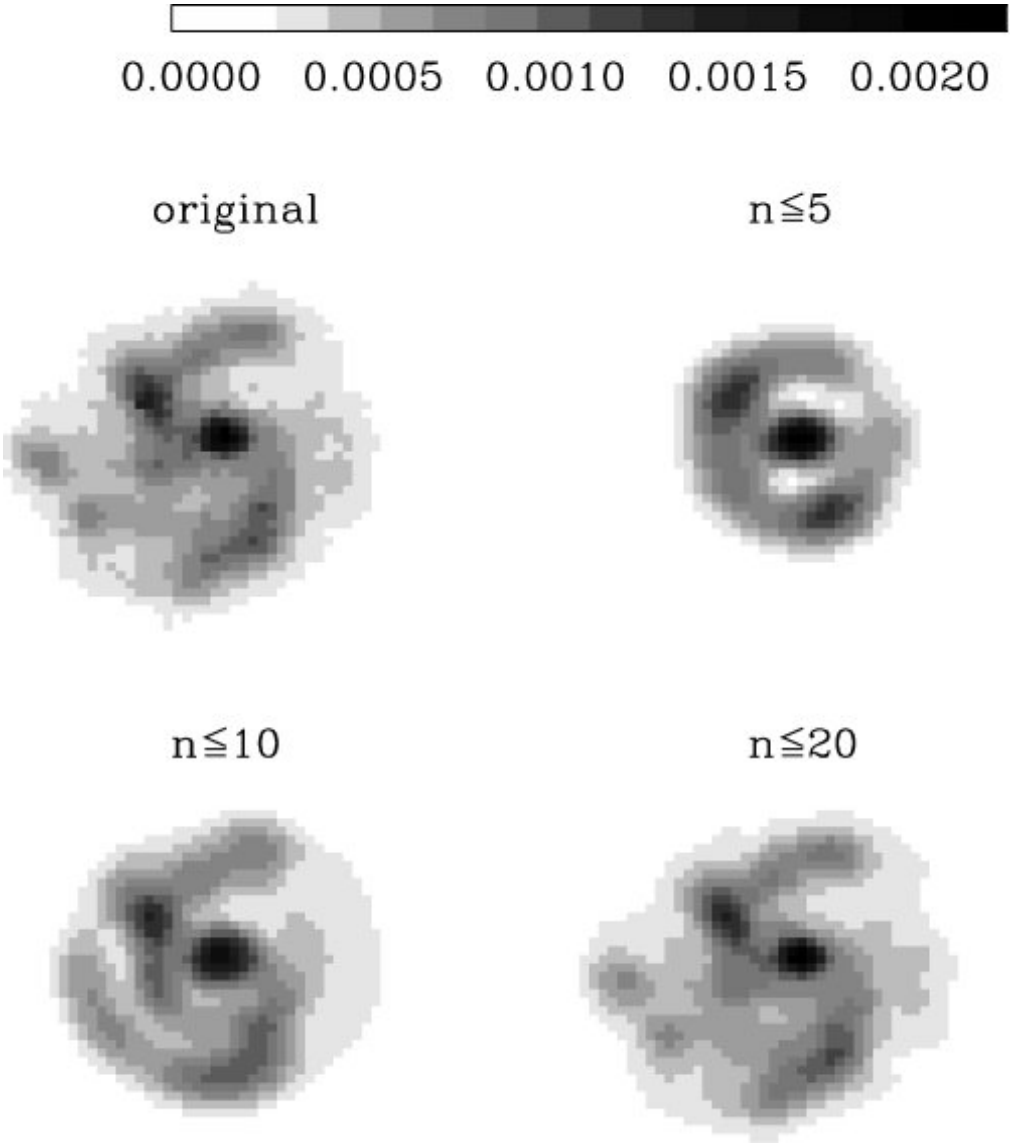
- Object detection (e.g. SExtractor)
- Choose possible models, e.g.:
  - exponential:
    $I(r) = I_0 \exp(-1.68 \frac{r}{r_e})$
  - de Vaucouleurs:
    $I(r) = I_0 \exp\left[-7.67(\frac{r}{r_e})^{1/4}\right]$
- Convolve with PSF (Gaussian, Double-Gaussian, Moffat).
- Fit the model parameters, the axis ratio, and the position angle.
- Report the likelihoods.
- Determine best-fit model or best-fit linear combination (`cmodel` mags in SDSS).

GaaP - Gaussian-aperture-and-PSF



from Refregier 2003, MNRAS, 338, 35

GaaP - Gaussian-aperture-and-PSF



from Refregier 2003, MNRAS, 338, 35

GaaP - Gaussian-aperture-and-PSF (flux)

How it's done:

- Object detection (e.g. SExtractor).
- Express PSF and objects as shapelet series.
- Deconvolve the object from the PSF (linear operation on the shapelet coefficients of the object)
- Calculate the Gaussian-aperture, Gaussian-PSF flux of the object (again done purely on the coefficients).
- For pixelised data, the shapelet decomposition of the object as well as the one of PSF leave flux residuals. When these are accounted for, GaaP can yield very accurate colours.