Automated morphometry with Sextractor and PSFEx

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DARK ENERGY SURVEY

cnrs UPMC PARIS UNIVERSITAS

Collaborators

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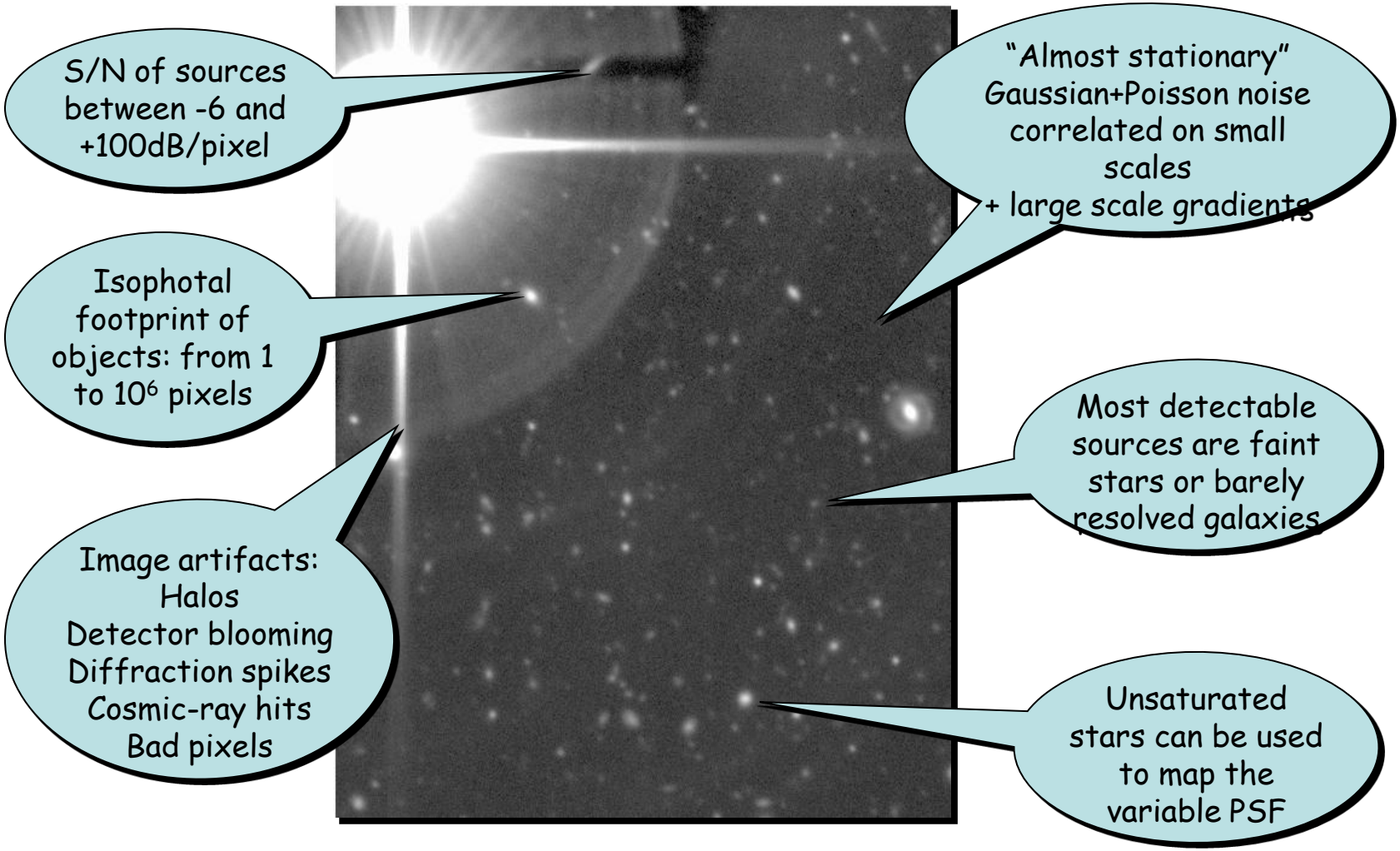
Philippe Delorme

Valérie de Lapparent

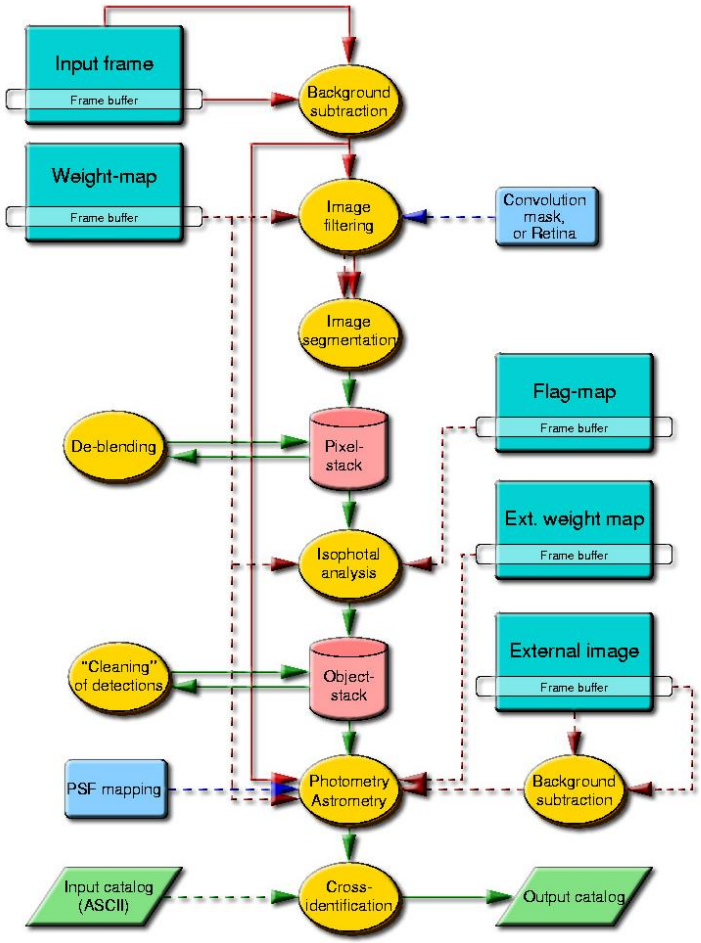
Gary Mamon

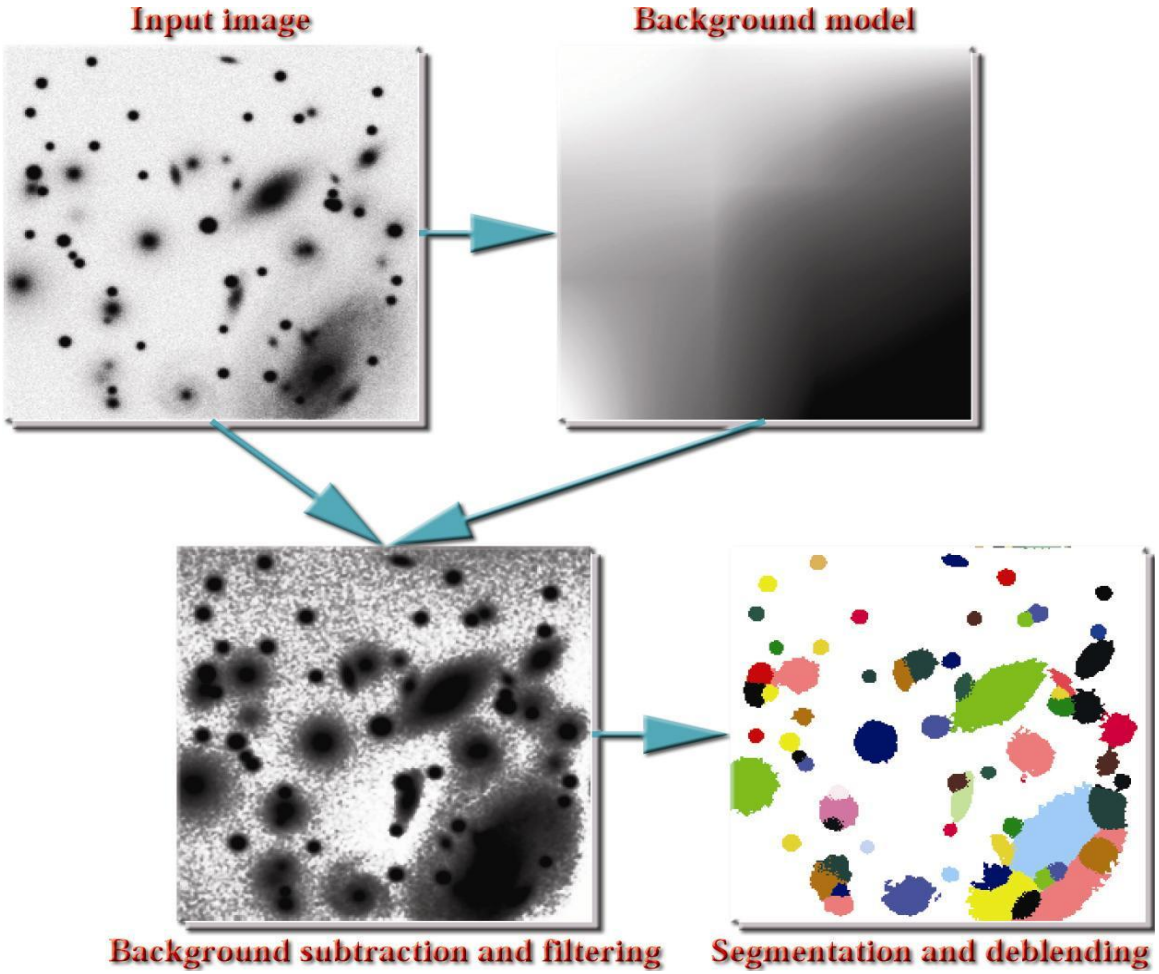
All wide-field astronomical images share similar features



... and 10^5 to 10^7 sources per square degree

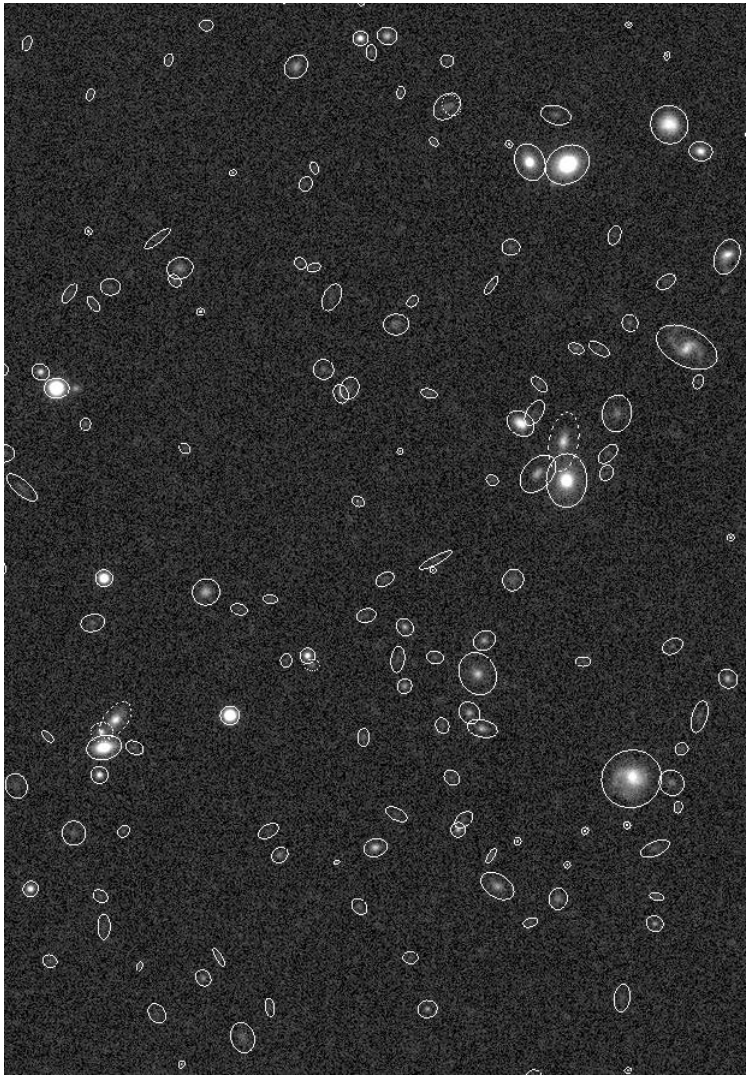
Source extraction with SExtractor





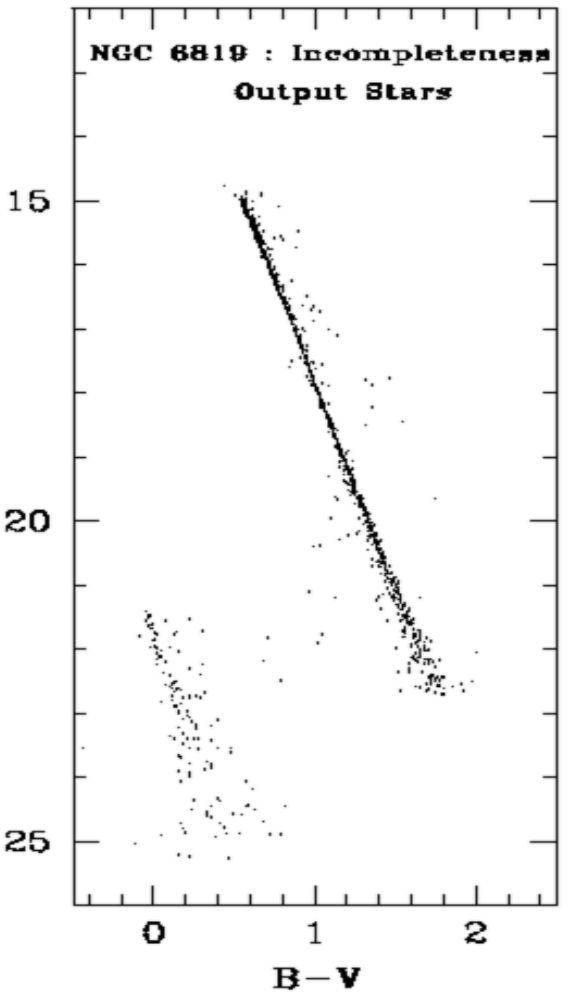
Galaxy model fitting

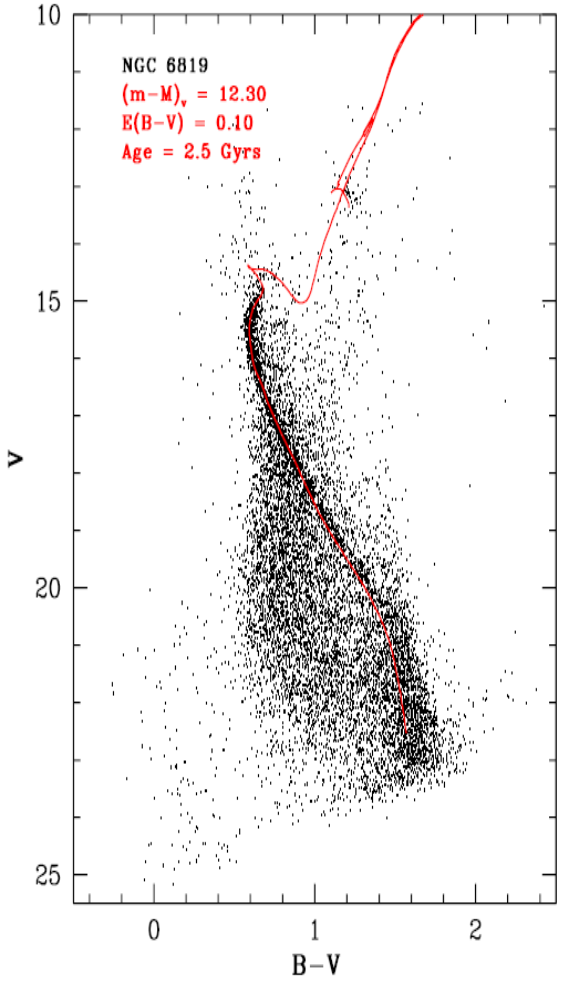
- Should be
  - fast
  - robust
  - fully automated
  - integrated in preexisting SExtractor code
- PSF model
  - Requires a first pass through the data
  - Modeling implemented in a separate tool: **PSFEx**



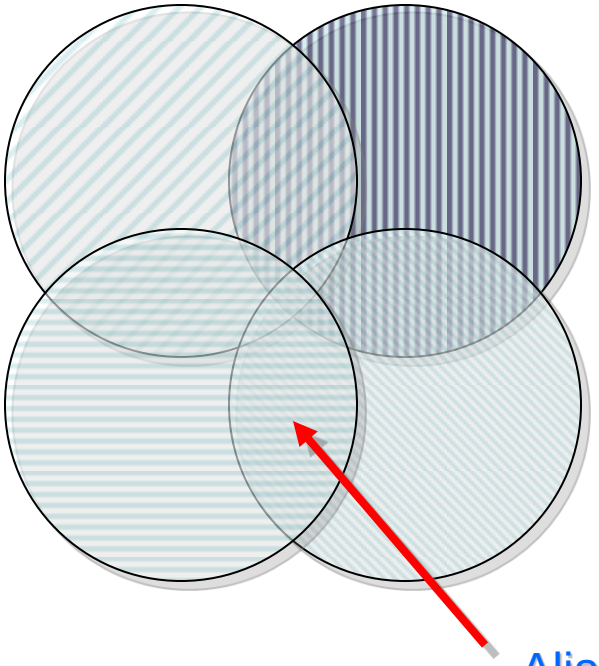
Experimenting with PSF modeling and fitting

- PSF modeling and fitting in PSFEx/SExtractor operating in an experimental way since 2001 (e.g. Cuillandre et al. 2001, Kalirai et al. 2001)
- Fitting routine fits groups of blended stars
  - currently maintained by Philippe Delorme.
- Much work went into handling arbitrary PSFs and undersampled data.



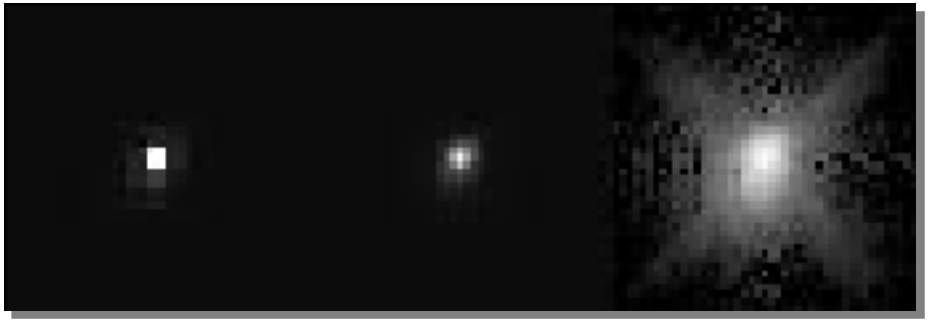


Modeling the PSF: Solving in Fourier space



Aliased portion of the spectrum

Reconstructed NICMOS PSF



Lauer 1999

Problem: noise is seldom stationary on astronomical images!

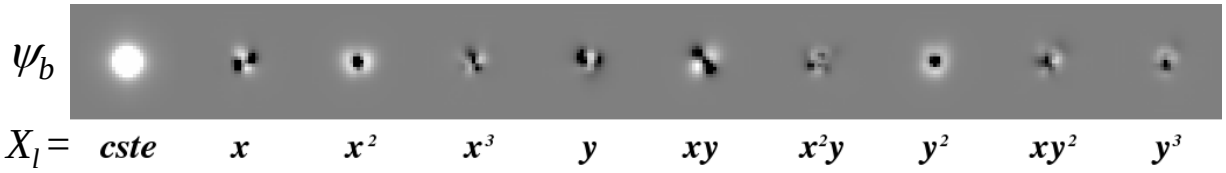
PSFEx: solving in direct space

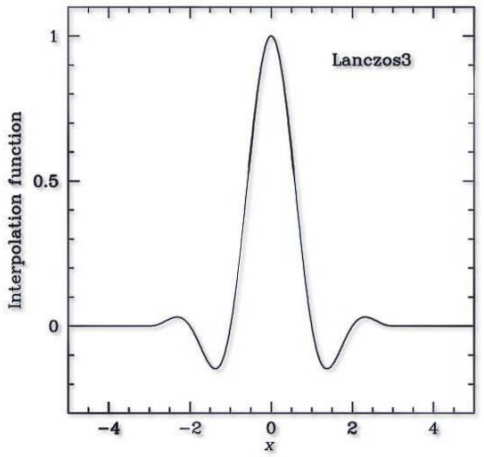
- A resampling kernel *h*, based on a compact interpolating function (*Lanczos3*), links the "super-tabulated" PSF to the real data: the pixel *j* of star *i* can be written as

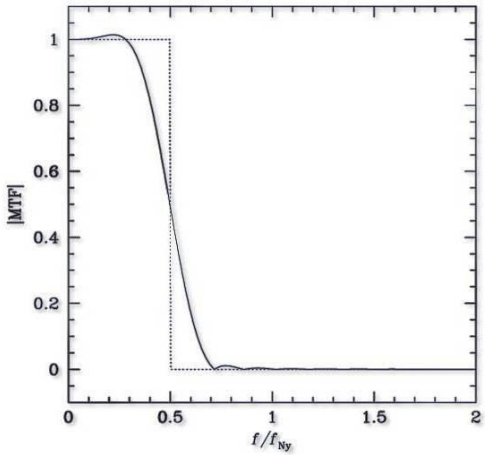
$$P_{ij} = a_i \sum_b \sum_k h_i\left(\boldsymbol{x}_k - \boldsymbol{x}_j\right) c_b \psi_{bk}$$

- The c_b's are derived using a weighted χ^2 minimization.
- The a_i's are obtained from "cleaned" aperture magnitude measurements
- Regularisation required for highly undersampled PSFs (FWHM <1.5 pixel)
  - ℓ^2 norm (Tikhonov)
- PSF variations are assumed to be a smooth function of object coordinates
  - ☞ The variations can be decomposed on a polynomial basis X_l

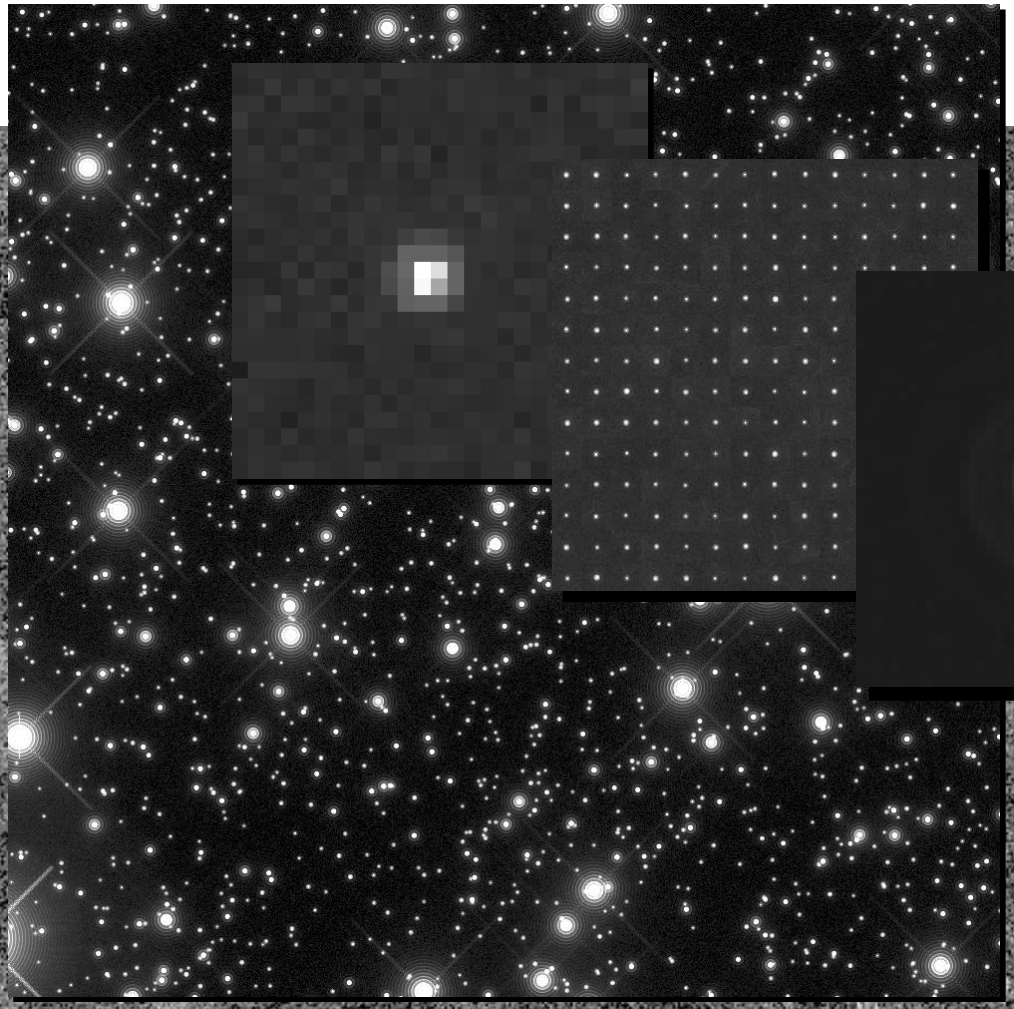
$$P_{ij} = a_i \sum_l X_l(\boldsymbol{x}_i) \sum_b \sum_k h_i\left(\boldsymbol{x}_k - \boldsymbol{x}_j\right) c_b \psi_{lbk}$$







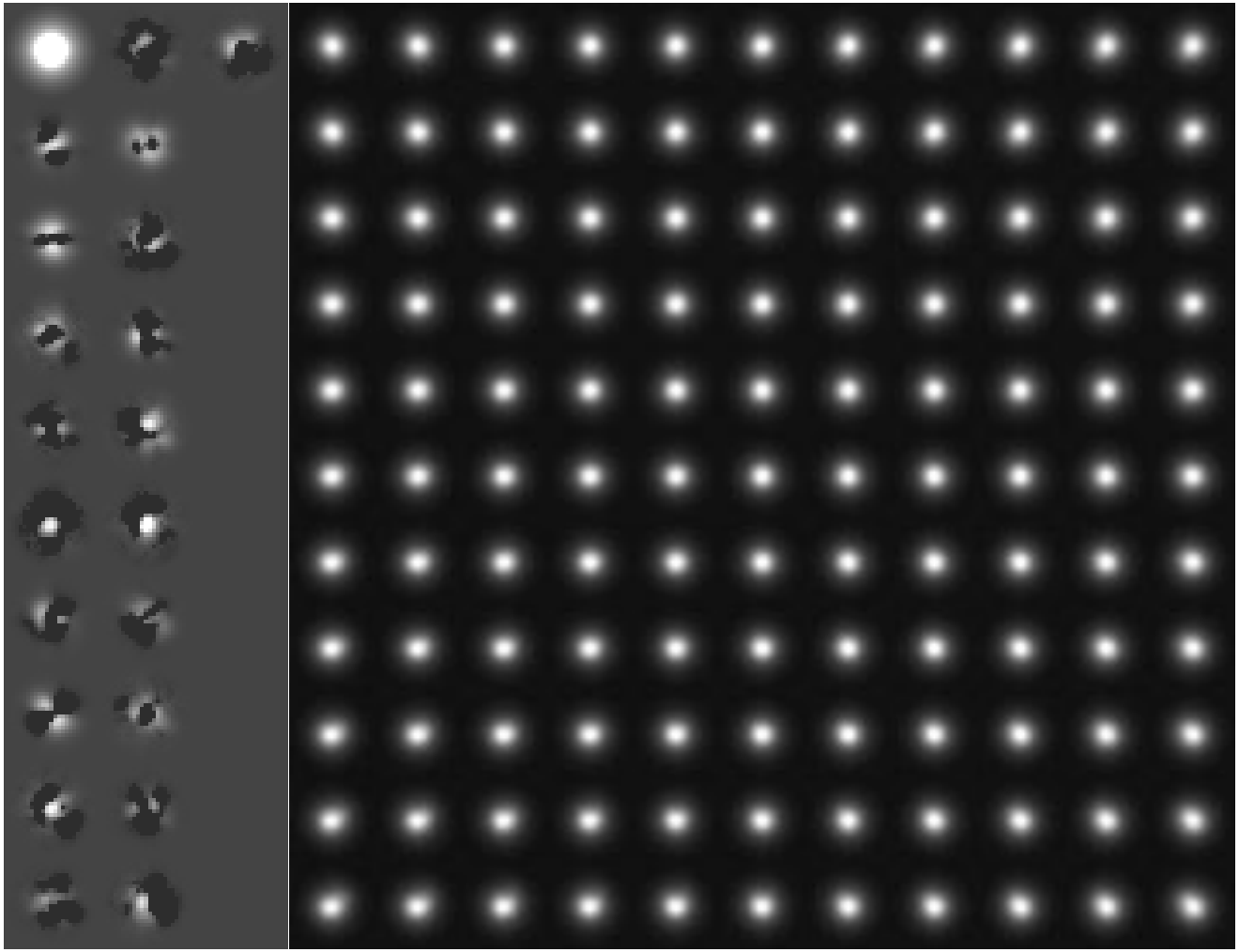
Recovered PSF with simulated, undersampled data



Diffraction-limited
FWHM ≈ 1pixel
Moderately crowded

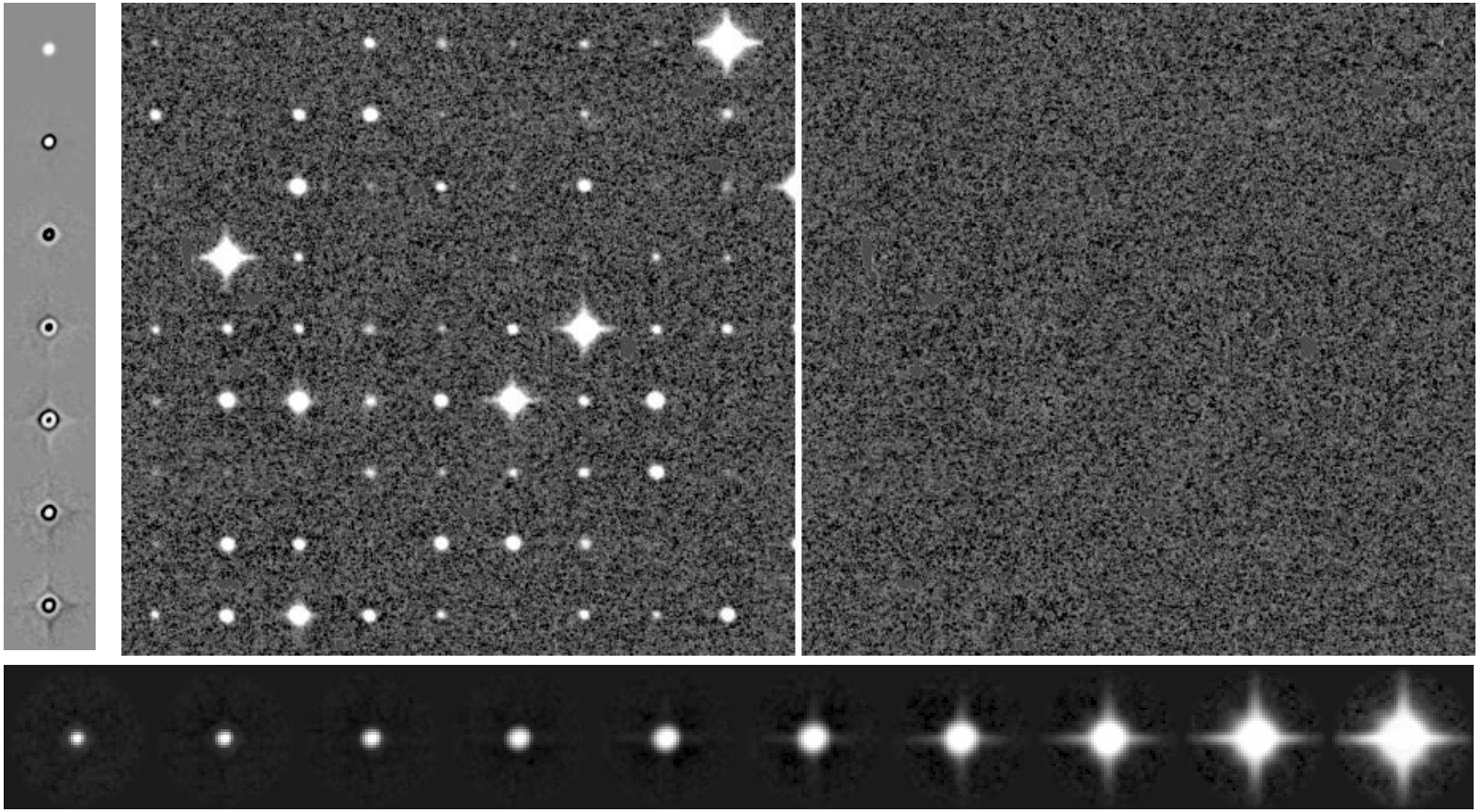
Modelling PSF variations: Reconstructed MEGACAM average PSF in the i-band

- 5th order polynomial in *x*,*y*: **`-PSFVAR_KEYS X_IMAGE,Y_IMAGE -PSFVAR_DEGREES 5`**
- Derived from 19,000 point sources
- χ^2/d.o.f. ~ 1.3
  - Proper motions make the PSF "noisy"
- Processing time ~ 100s on a 2GHz processor



PSF modeling on “non-linear” media

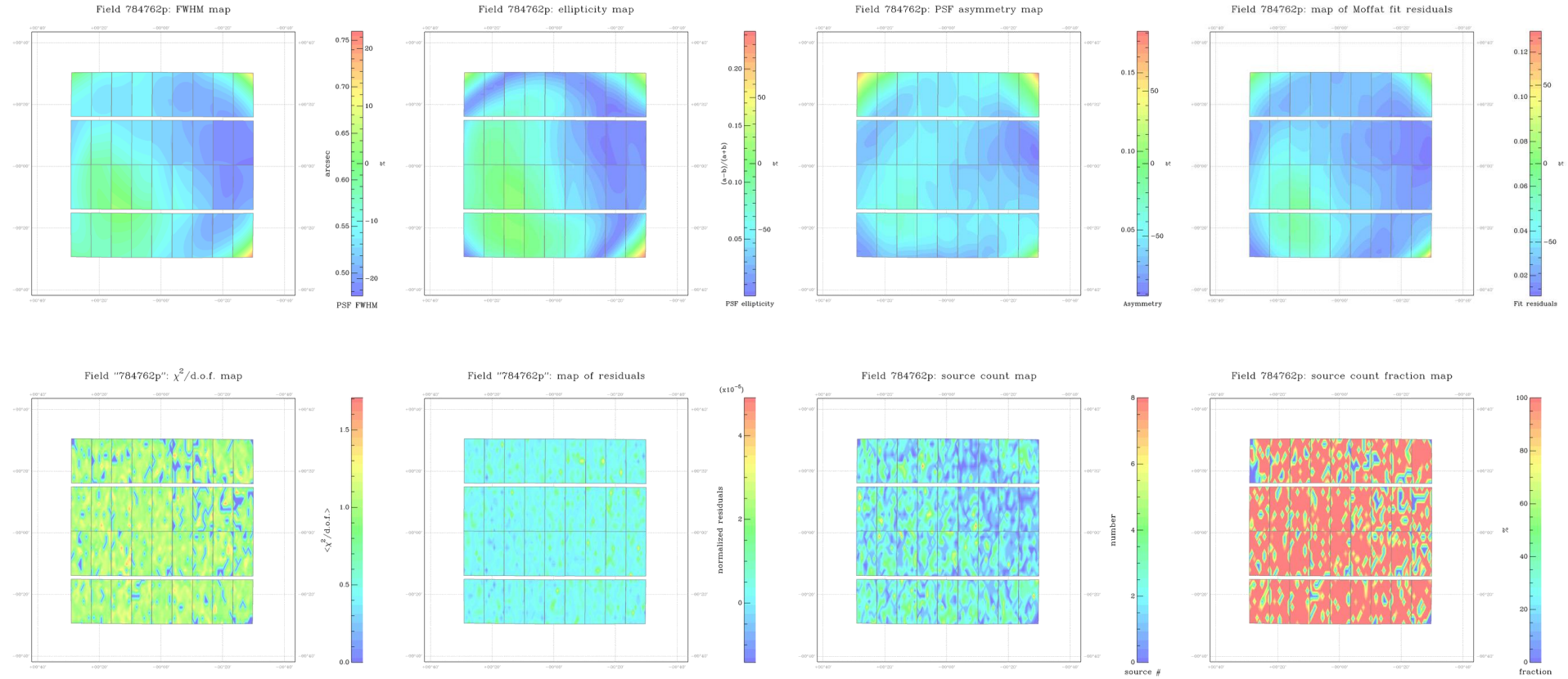
- 1670 point-sources from the central 4096×4096 pixels of a photographic scan (SERC J #418 survey plate, courtesy of J. Guibert, CAI) FWHM ≈ 3pixel
- 6th order polynomial in MAG_AUTO



PSFEx quality control and metadata

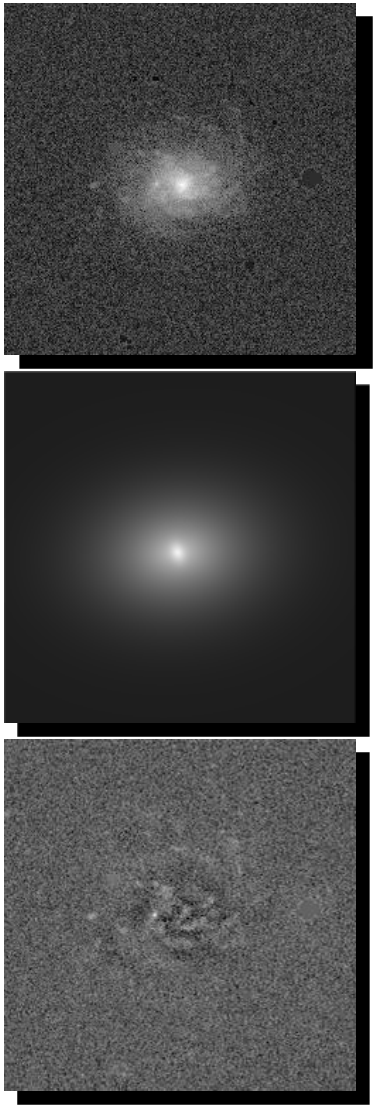
- PSFEx runs a variety of diagnostics
  - Various 2D histograms are produced
  - Numbers are written to a metadata file in XML-VOTable format at the end of each run.
    - An XSLT stylesheet that translates to HTML comes with the PSFEx package.
    - High level libraries such as vo.table for Python can be used to parse the VOTable

PSFEx quality control (cont.)

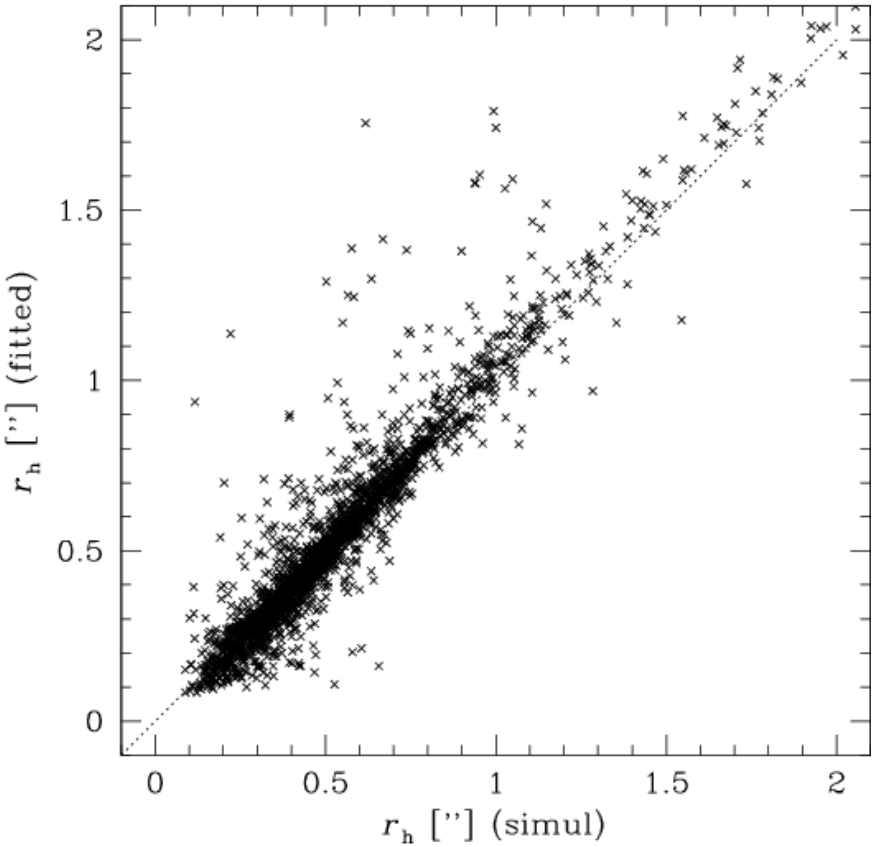


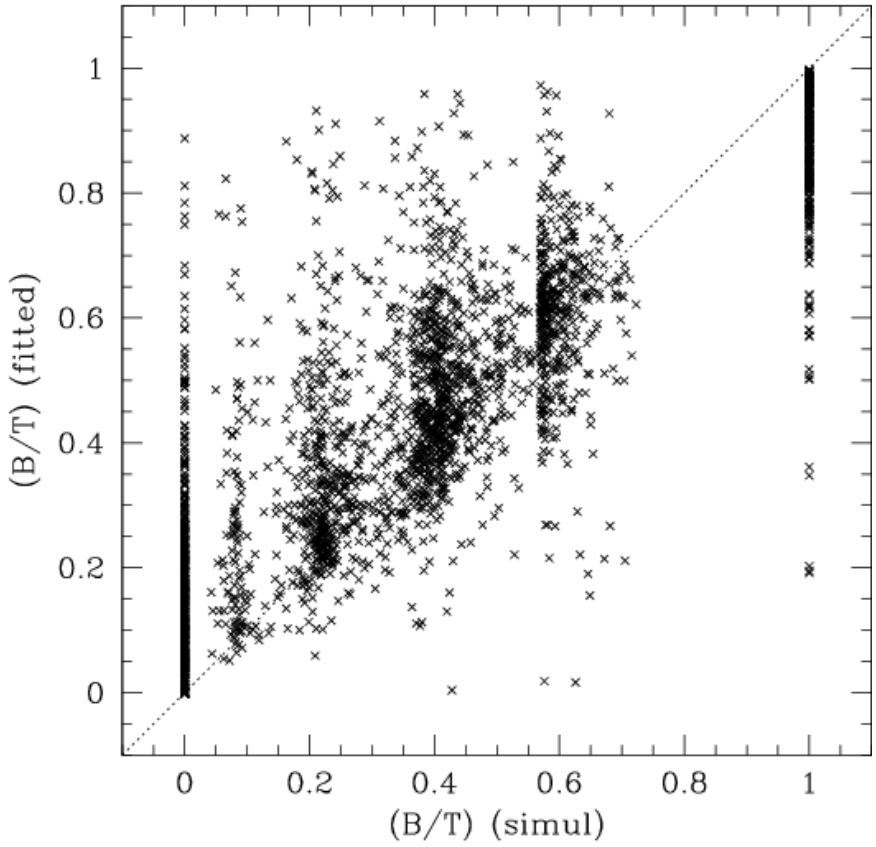
SExtractor morphometry

- PSF modeled using ***PSFEx***
  - Sampling automatically adjusted depending on image
- Models are computed using a grid size that depends on sampling and on the object
  - Image and model rasters are rebinned for very large objects
- Several model components currently available:
  - Background level, Point source (2 + 1 free parameters), Sersic (2 + 5), De Vaucouleurs (2 + 4), Exponential (2 + 4)
  - others currently in development
  - The presence of model parameters in the Sextractor `.param` file triggers the fitting process
- Minimization uses the ***LevMar*** implementation of the Levenberg-Marquardt algorithm by M.Lourakis
  - Adaptive Jacobian
  - Initial parameter guesses made from « classical » SExtractor measurements
  - Robust fitting
  - Bright pixels from neighbours automatically masked by SExtractor.
- Processing speed: 10-30 galaxies/s on a single 3GHz CPU core.
  - ~ one million galaxies per day and per compute node.



Recovered galaxy parameters

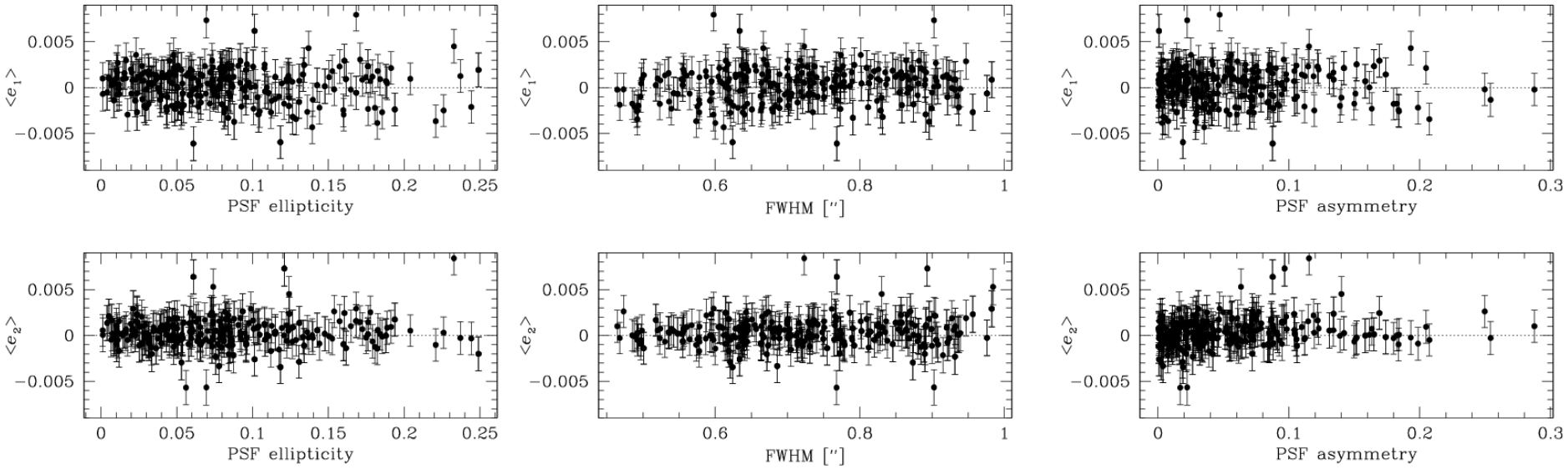




Sersic (n=4) + Exponential fit for i<21

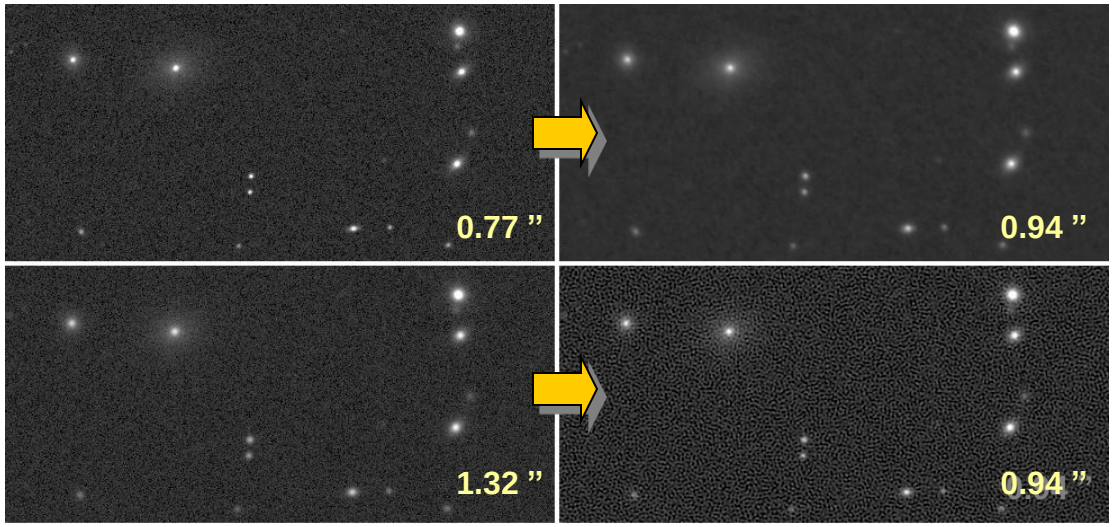
Weak shear measurements with SExtractor

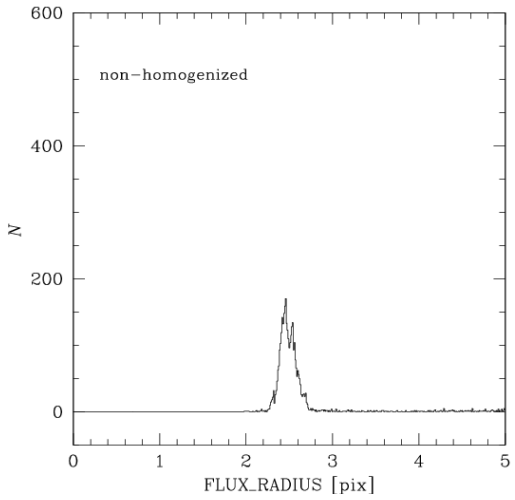
- trends as a function of PSF ellipticity, FWHM, or asymmetry kept below the 10^{-3} level

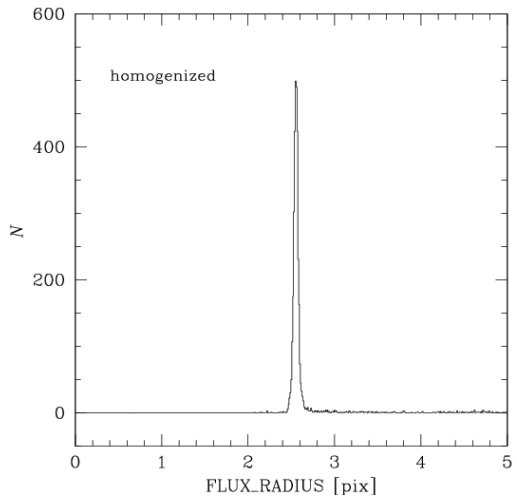


PSF homogenization in the Dark Energy Survey

- Co-addition: large pointing offsets + small number of exposures create jumps in the PSF at image boundaries
  - Combine exposures with variable image quality
  - ➔ PSF homogenization required
  - Bring all images to the same, circular PSF, using the variable PSF models
  - "Cheap" alternative to image fusion/Bayesian inference.
    - DECam images are properly sampled
    - Impose the target PSF with median seeing to minimize noise correlation
  - Handle noise correlations on arcsec scales
  - Masking and interpolation critical

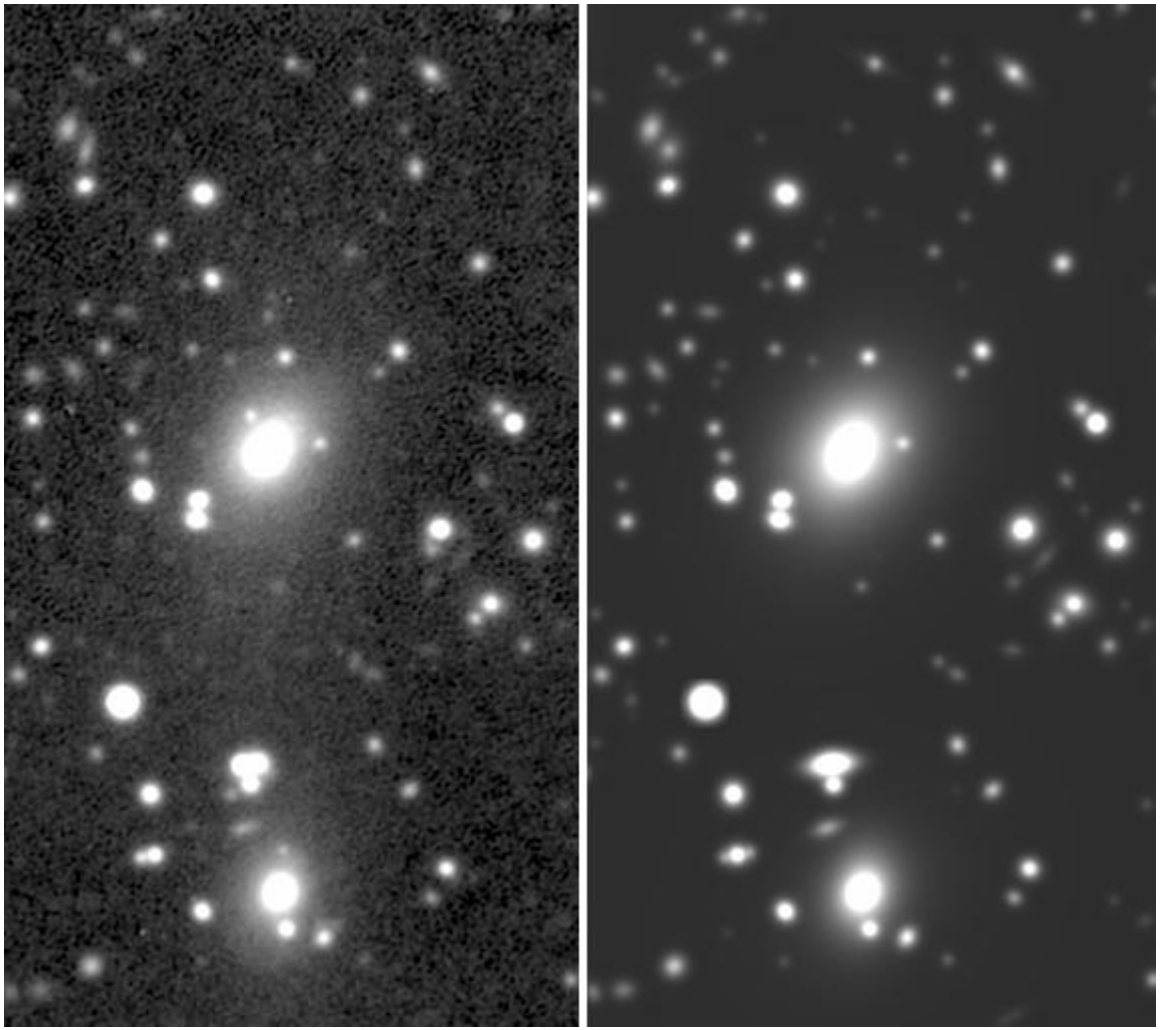






Future plans and improvements

- Multi-threading
- Multi-source model-fitting
- Intelligent deblending
- Improved background model
- Multi-band model-fitting



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