AIDA – Astronomical Image Decomposition & Analysis

an interactive advanced tool for 2D photometric and morphological analysis

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Astrosiesta 22/04/2010

Detection of quasar hosts

Telescope+detector →

quasar image = (galaxy+ nucleus) ⊗ PSF

- If PSF is known → simultaneous decomposition into nuclear & host components by model fitting

- correct decoupling of the shape of the host galaxy and shape of the PSF requires 2d modeling (Taylor, Dunlop et al. 1996, Kuhlbrodt et al. 2004, Peng et al. 2002)

- 2 main tasks:
  - PSF modelling
  - Target model fitting

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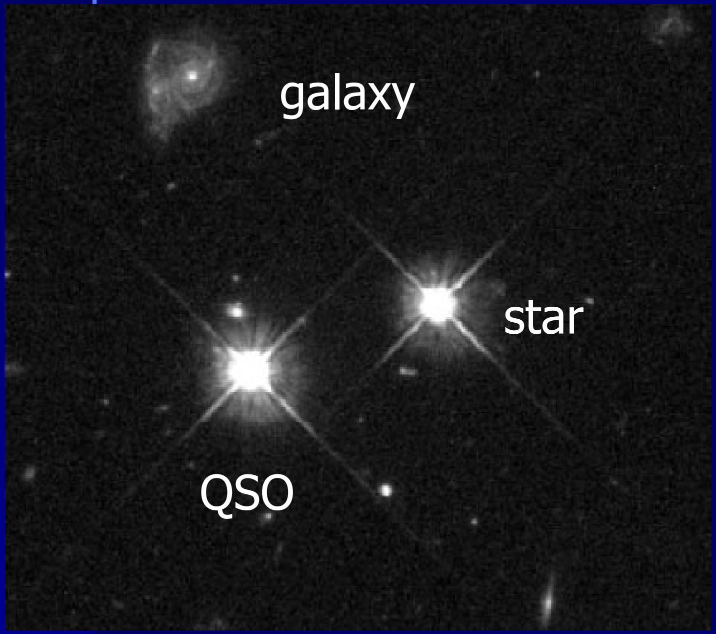
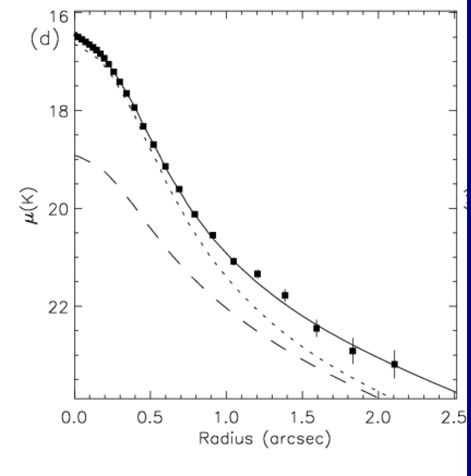
As the name suggests …



They really look like stars !



And going to higher z:

↓

cosmological dimming of s.b.$\propto$ $(1+z)^4$

↓

The host galaxy becomes very faint compared to the nucleus !!!

Detection of quasar hosts at high-z

- To detect & (possibly) characterize high z quasars hosts is required:
  - High spatial resolution (narrow PSF)
  - Good sensitivity (large telescope)

  $\Rightarrow$ HST, AO

  But … complex PSF shape, variable in the FOV
- Detection of the faint extended emission surrounding a bright point source obviously requires careful characterization of the PSF

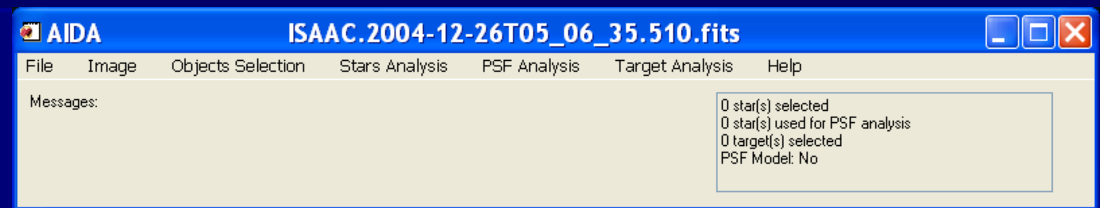
PSF modelling

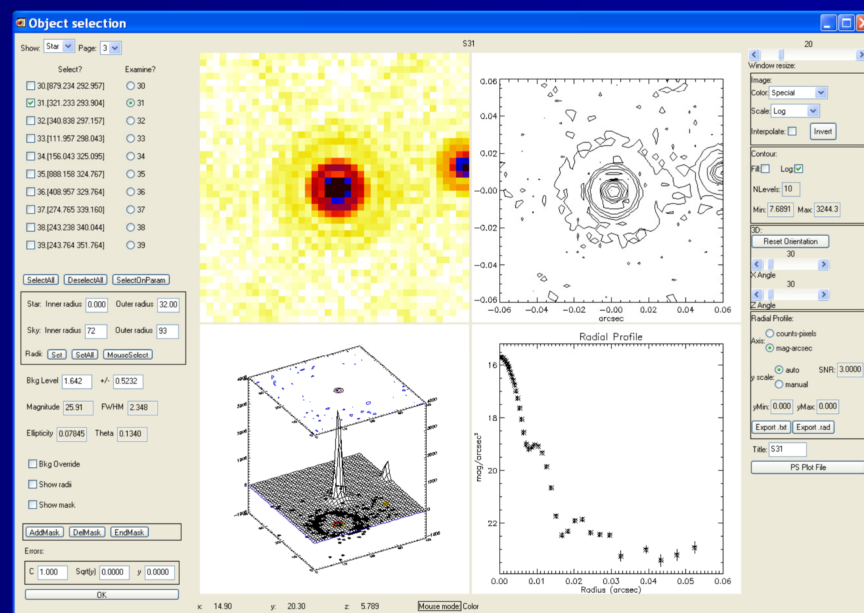
- **PSF can vary over time and with the location in the FOV**
- We need to know what the PSF shape was
  - (1) at the location of the target,
  - (2) when the exposure has been taken &
  - (3) with the exact configuration used
- If possible, use stars in the FOV as reference (2&3), modeling them and characterizing space-dependent variation of the PSF and extrapolating the PSF shape at the target location (1)
- Not always feasible (depends on the FOV and on the target field) $\rightarrow$ stars images taken in conditions as close as possible

AIDA Overview

Tested under Windows XP/Vista, Linux SuSE / Red Hat, MacOS
No IDL license required

- Developed in IDL, based on Widgets GUIs (but /NOWIDGET batch mode available for large datasets)
- Main guide lines:
  - user-friendly
  - highly interactive
  - able to provide results with little user intervention …
  - but also allowing the user to customize each step of the analysis

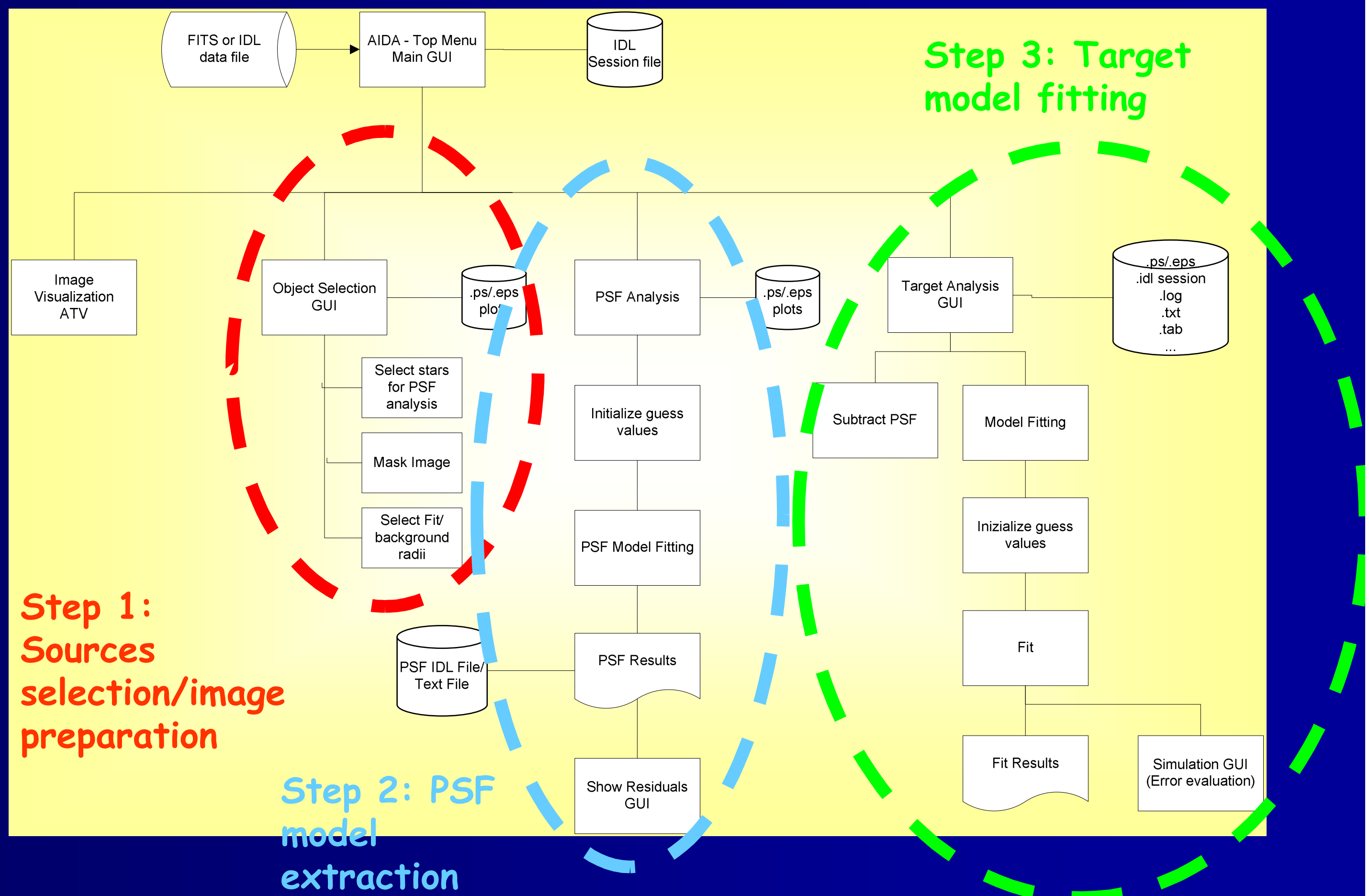




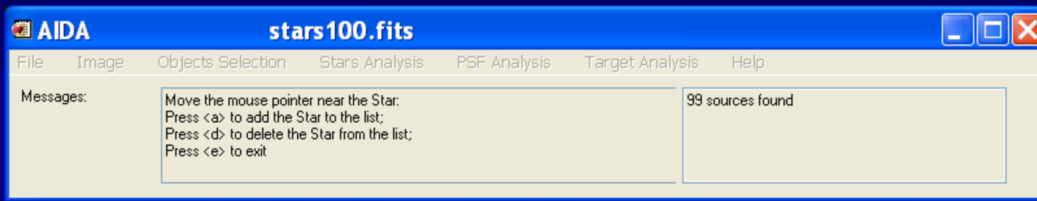
AIDA Overview

Provides support from the raw image to the object characteristics parameters

- Step 1: Sources selection/image preparation
- Step 2: PSF model extraction
- Step 3: Target model fitting



Sources selection/image preparation



Info/Help area

Image visualization based on a modified version of ATV (Barth, A. J. 2001)

Selection of the target to be analyzed and of stars to be used in the PSF analysis

- First selection based on FWHM, SNR, sharpness, roundness
- Produce text & graphic reports to help the final choice

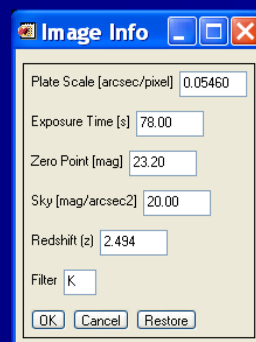
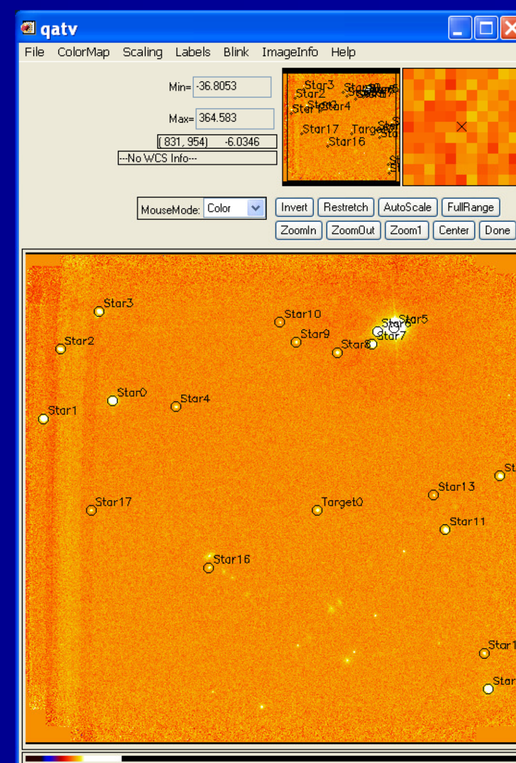
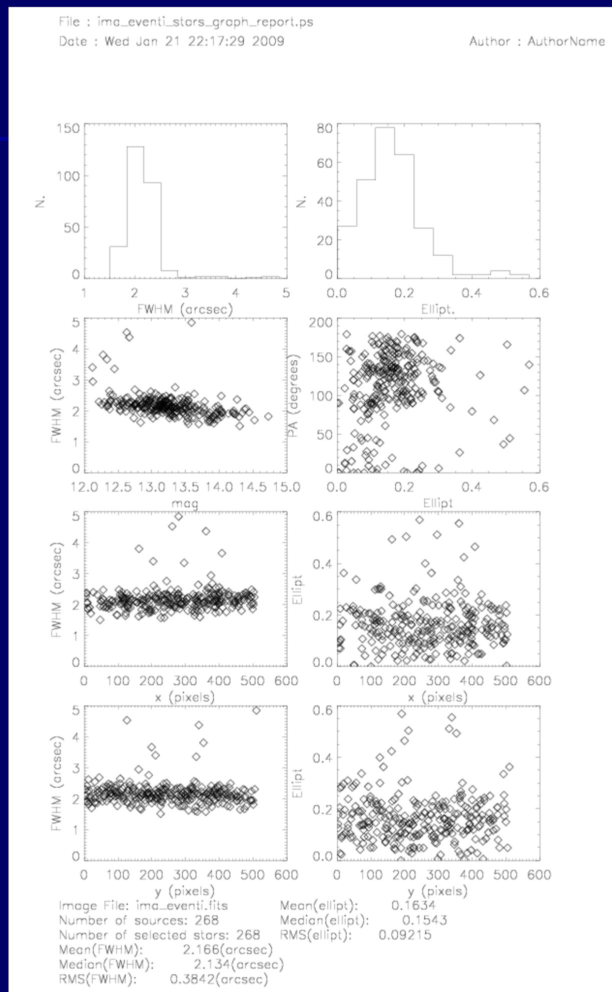
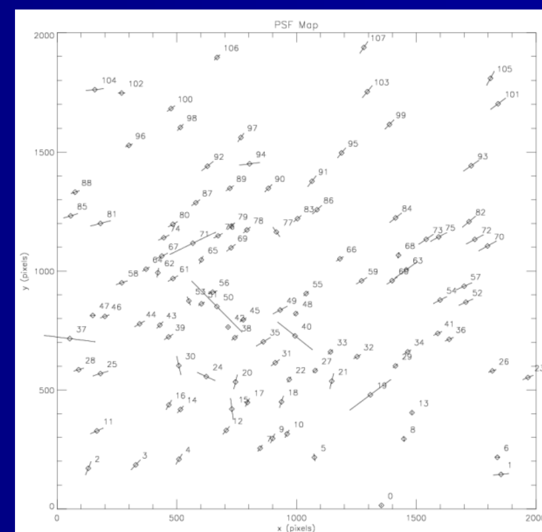


Image info: some parameters are extracted from FITS keywords



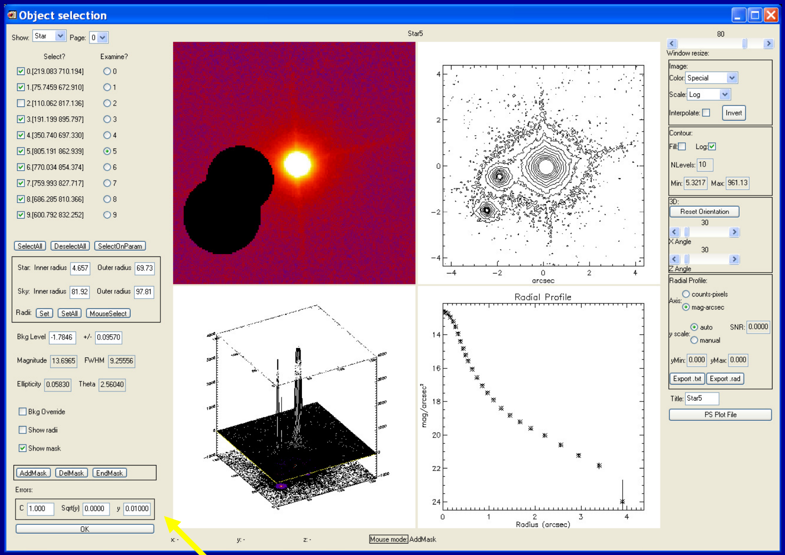

File : ima_eventi_stars_graph_report.ps
Date : Wed Jan 21 22:17:29 2009
Author : AuthorName
FWHM (arcsec)
Ellipt.
mag
PA (degrees)
x (pixels)
y (pixels)
Image File: ima_eventi.fits
Number of sources: 268
Number of selected stars: 268
Mean(FWHM): 2.166(arcsec)
Median(FWHM): 2.134(arcsec)
RMS(FWHM): 0.3842(arcsec)
Mean(ellipt): 0.1634
Median(ellipt): 0.1543
RMS(ellipt): 0.09215


PSF Map
x (pixels)
y (pixels)

Sources selection/image preparation

For each source:

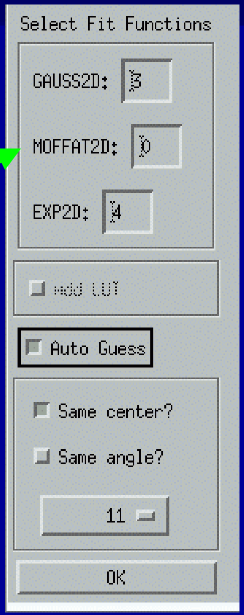
- Mask the image (exclude bad pixels, contamination from other sources, …)
- Define the region to be included in the fit (exclude saturated or low SNR regions)
- Compute local background

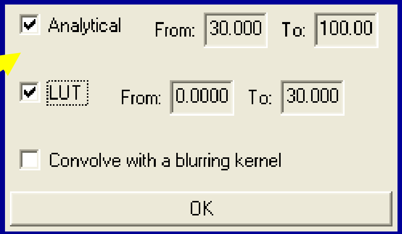


Choose fit weighting model

AIDA PSF Models

- PSF models: analytical (any combination of provided 2d-functions) and/or empirical (e.g. TinyTim)
- 2d functions:
  - Gauss
  - Moffat
  - Exponential
  - User defined functions …
- Also 2 different regions with different PSF models (e.g.: LUT in the core and mixed in the wings → HST)





PSF modelling

Multiple stars fitting:

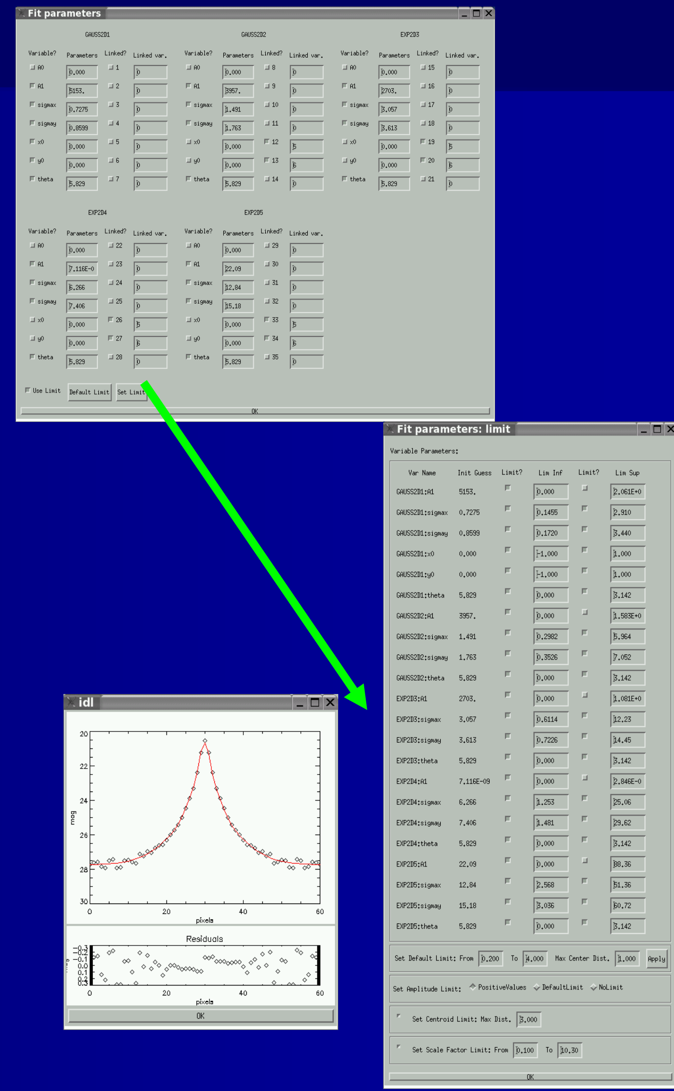
- simultaneous fitting with the same parameters

or

- individual stars fitting (to model PSF changes in the FOV) $\rightarrow$ using analytical models with a limited number of parameters, dependence of the PSF parameters on the position can be modeled

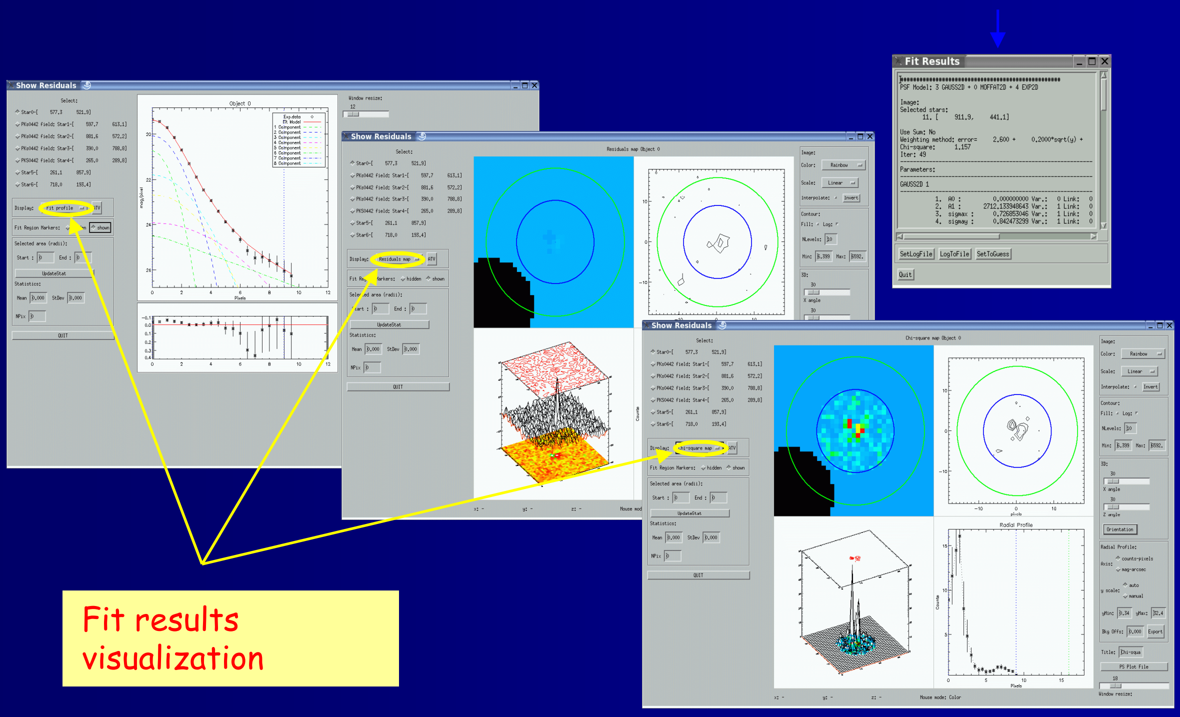
Model fitting: initial guesses

- ⇒ … initial guess & constraints automatically, basing on fitting isophotes of the highest SNR star with ellipses and 1-d fitting of the radial profile, so that the intervention of the user is hardly ever required



PSF Fit results

Text log file of the fit results

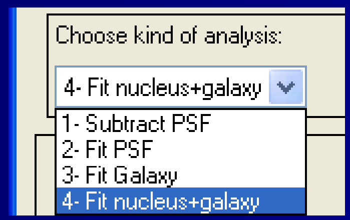


Fit results visualization

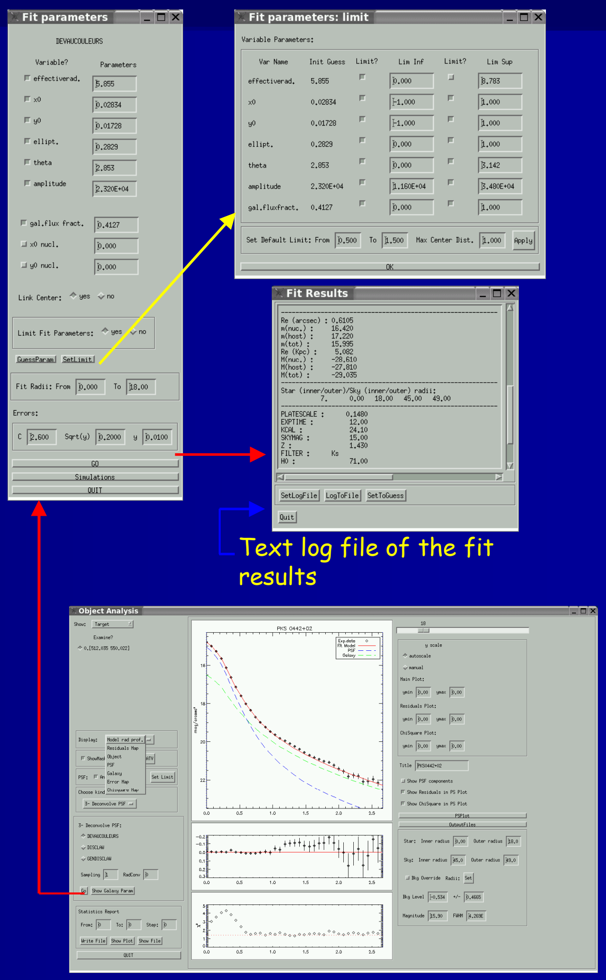
Target model fitting

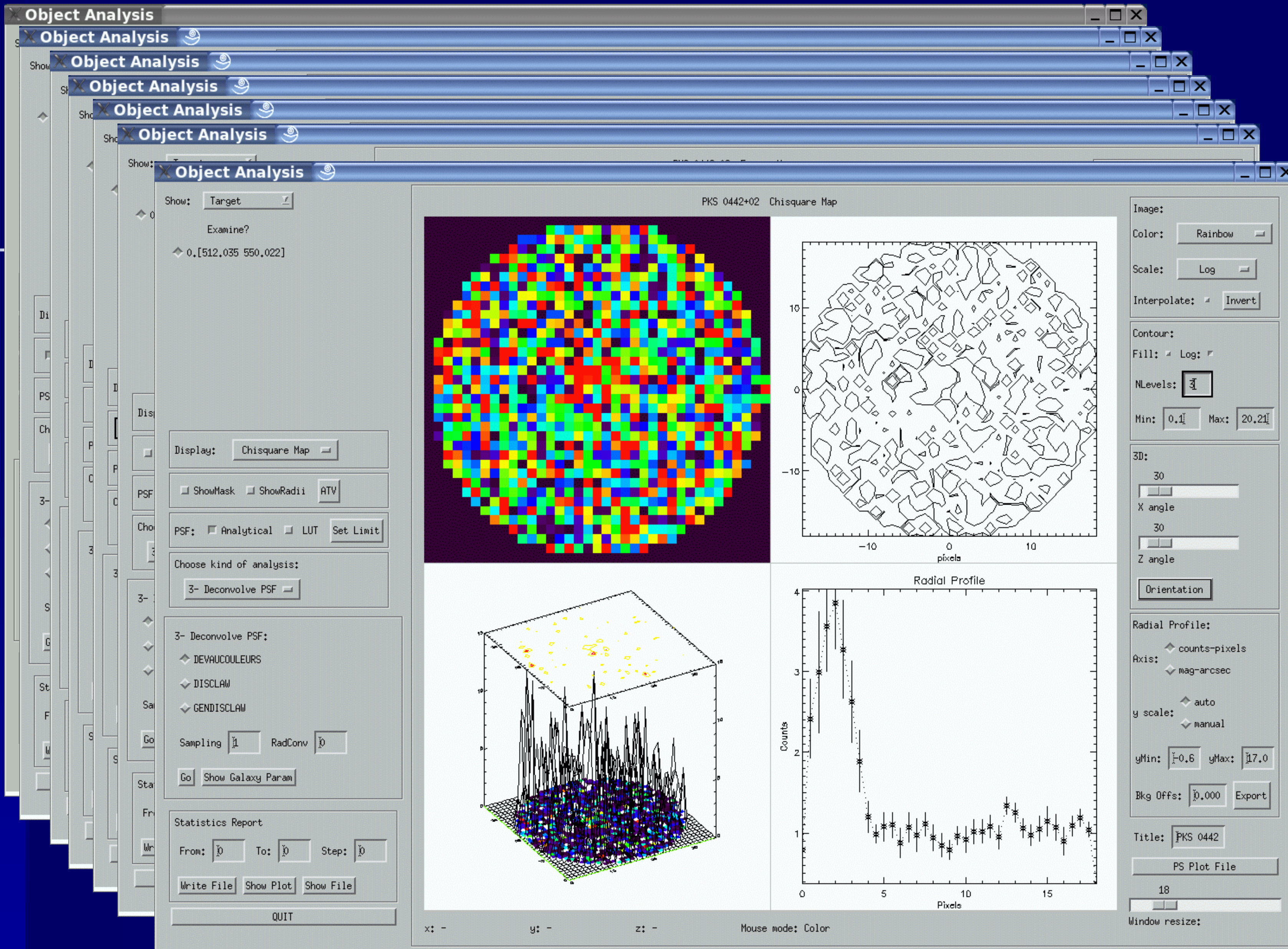
(galaxy+nucleus) ⊗ PSF

- Galaxy models:
  - De Vaucouleurs
  - Disc Law
  - Generalized (Sersic) Law
  - No galaxy
  - … (user dfeined functions)



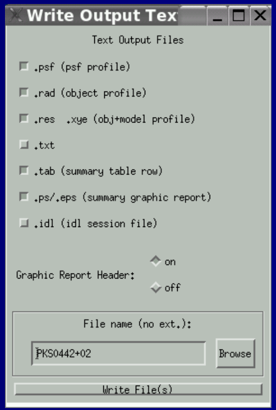
- Initial guesses can be computed by the procedure
- To minimize the dependency on the initial guesses, a procedure can compute the fit with different starting points, randomly extracted in a suitable range



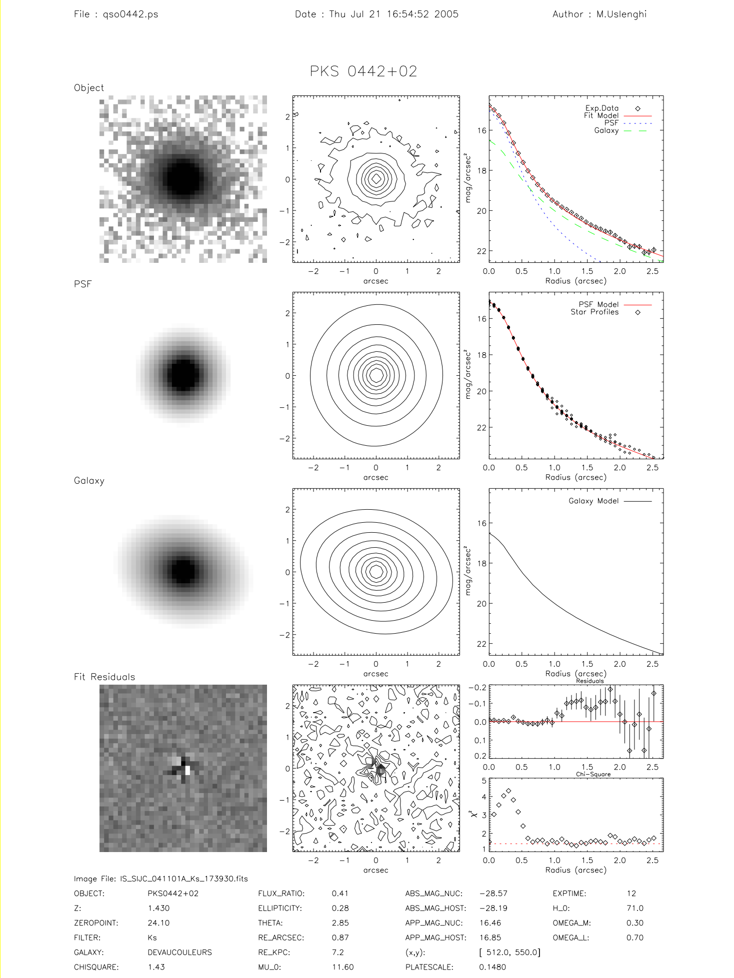

Object Analysis
Show: Target
Examine?
0.[512.035 550.022]
Display: Chisquare Map
ShowMask ShowRadii ATV
PSF: Analytical LUT Set Limit
Choose kind of analysis:
3- Deconvolve PSF
3- Deconvolve PSF:
DEVAUCOULEURS
DISCLAW
GENDISCLAW
Sampling RadConv
Go Show Galaxy Param
Statistics Report
From: To: Step:
Write File Show Plot Show File
QUIT
PKS 0442+02 Chisquare Map
Radial Profile
Counts
Pixels
pixels
Image:
Color: Rainbow
Scale: Log
Interpolate: Invert
Contour:
Fill: Log:
NLevels:
Min: 0.1 Max: 20.21
3D:
X angle
Z angle
Orientation
Radial Profile:
Axis: counts-pixels mag-arcsec
y scale: auto manual
yMin: -0.6 yMax: 17.0
Bkg Offs: 0.000 Export
Title: PKS 0442
PS Plot File
Window resize:
Mouse mode: Color

Target model fitting - results

- Output files can be generated in several formats, e.g:
  - Text files
  - Session IDL file
  - PS files

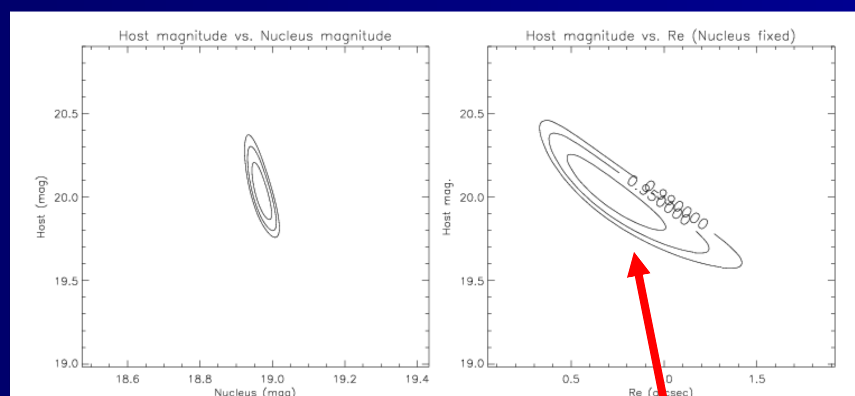


- Example of PS graphic report including relevant plots & results of the analysis



Error evaluation - χ^2 maps

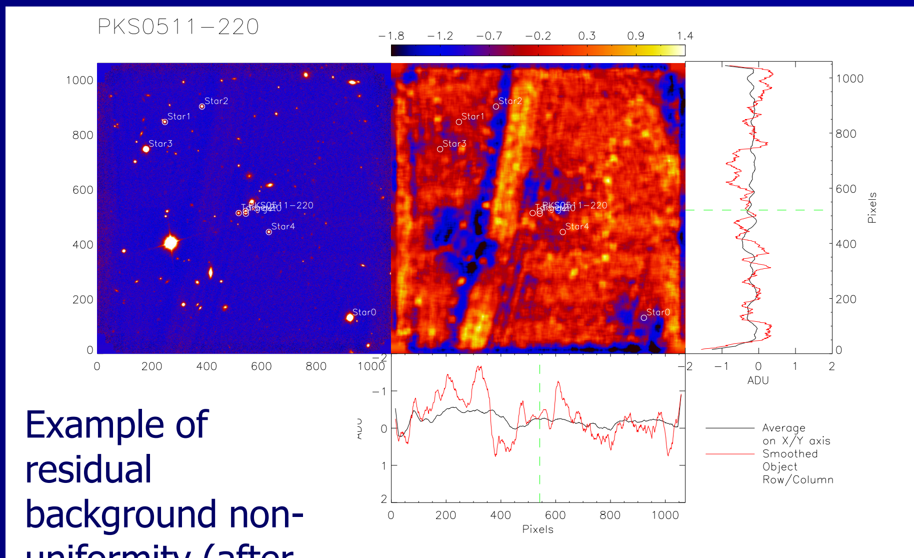
- Put reliable error bars on the results is as important as producing the results (and more tricky …)



Correlation between galaxy radius & magnitude

Error evaluation

- Various systematic errors, not normally distributed:
  - Local background uncertainty (especially for NIR images)
  - Some PSF model inadequacy
  - Undersampling
  - …
- Not easy evaluate their propagation

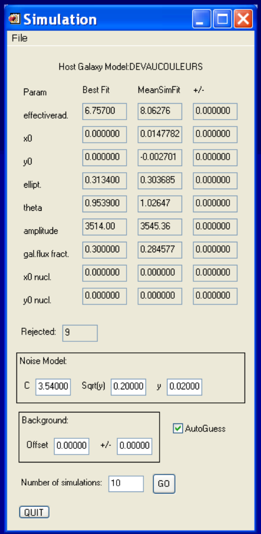


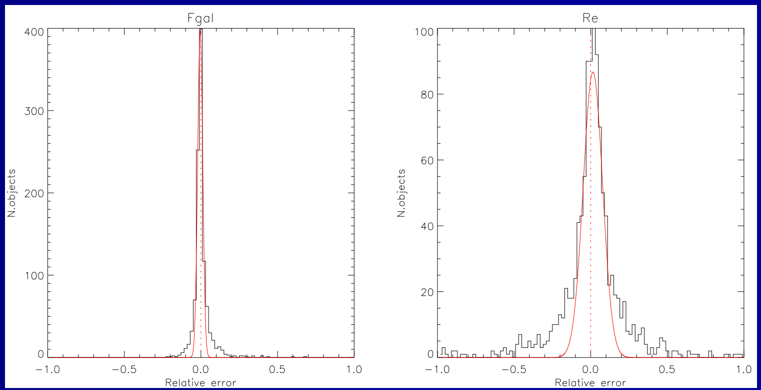
Example of residual background non-uniformity (after bkg subtraction) in NIR image

Error evaluation

- A simulation tool (→ to build & analyze synthetic images) has been implemented:

  synthetic quasars images are generated adding noise to the best fit model - then, the fit procedure is applied to the images, producing a "best fit" combination of parameters values for each image





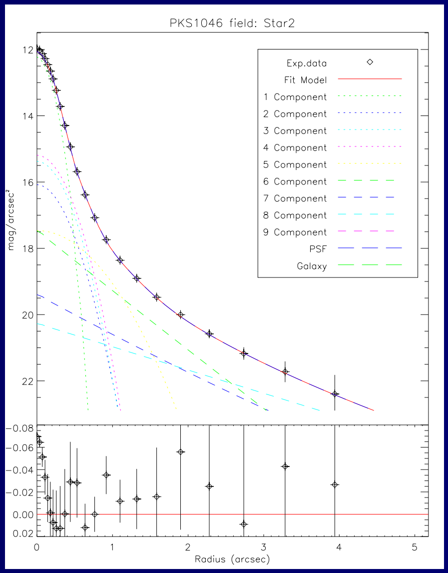
Examples with astronomical data

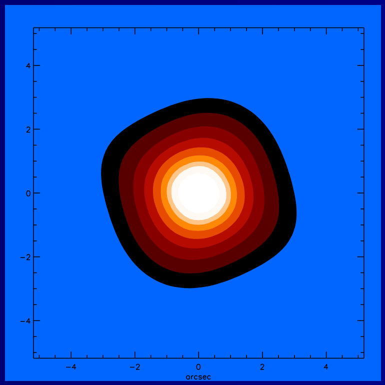
We used AIDA to analyze several astronomical data sets (taken with different instruments):

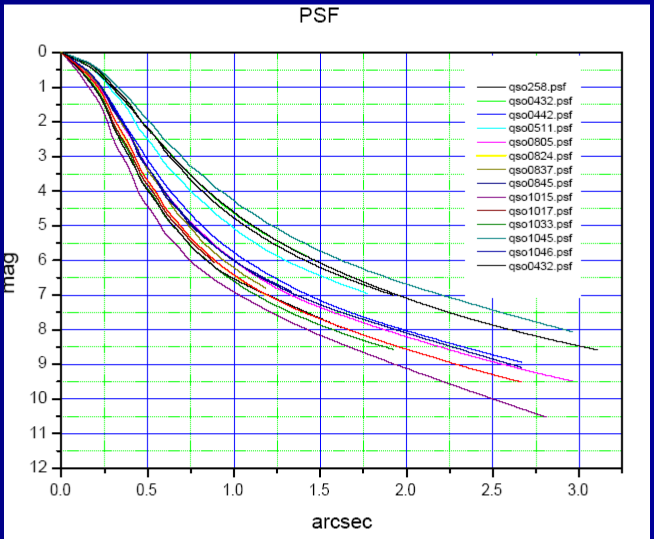
- VLT/ISAAC
- NOT/NOTCam (NIR)
- HST/WFPC2
- VLT/NACO
- MAD

VLT/ISAAC

- Fully analytical PSF (~ 5 gaussians + 3 exponentials)
- PSF invariant in (a large area of) the FOV

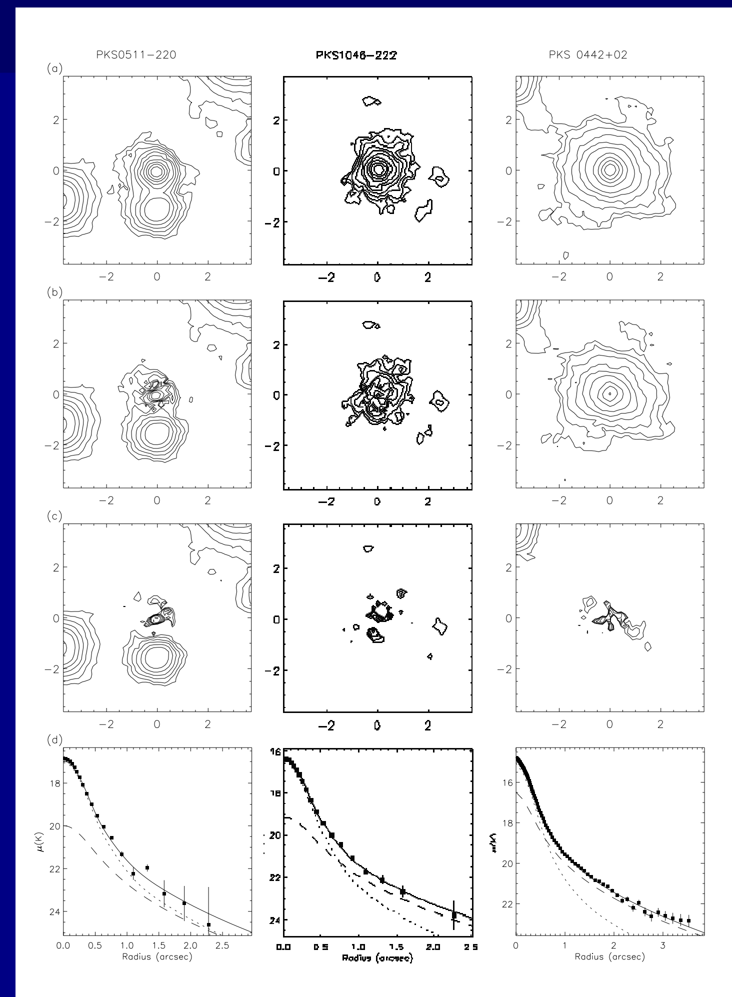






VLT/ISAAC Results

Quasar	z	Filter	m_{nuc}[a]	m_{host}[a]	r_e (arcsec)	χ^2_{DV}[b]	χ^2_{DL}[c]	χ^2_{PSF}[d]
Radio Quiet Quasars								
Q 0335-3546	1.841	K	17.9	20.1±0.4	1.1±0.5	0.6	0.4	1.4
MS 0824.2+0327	1.431	K	18.4	18.1±0.1	0.5±0.1	1.0	1.1	19.0
2QZ J101733-0049	1.342	H	19.0	20.2±0.3	0.9±0.2	1.3	1.2	4.2
2QZ J101733-0203	1.895	K	18.8	19.9±0.2	1.0±0.6	1.6	1.3	4.0
TOL 1033.1-27.3	1.610	K	19.2	17.3±0.1	0.6±0.1	3.6	1.5	67.1
Q 1045+056	1.230	H	17.4	>20.1	...	-	-	0.9
Radio Loud Quasars								
PKS 0258+011	1.221	H	17.5	19.0±0.2	0.7±0.2	0.8	1.0	6.6
PKS 0432-148	1.899	K	17.2	19.6±0.3	1.2±0.2	1.2	1.5	2.0
PKS 0442+02	1.430	K	16.5	16.8±0.1	0.8±0.2	1.1	3.5	33.5
PKS 0511-220	1.296	H	18.1	19.5±0.3	0.7±0.2	1.5	1.6	3.5
PKS 0805-07	1.837	K	16.0	19.2±***	0.6±***	-	-	0.9
PKS 0837+035	1.570	K	17.6	19.3±0.3	0.9±0.3	1.0	2.4	4.1
PKS 0845-051	1.242	H	17.8	18.2±0.1	0.6±0.2	0.5	7.9	38.7
PKS 1015-31	1.346	H	16.1	18.1±0.1	0.9±0.2	1.0	2.3	17.7
PKS 1046-222	1.609	K	17.9	18.7±0.2	0.7±0.2	1.2	1.2	10.3



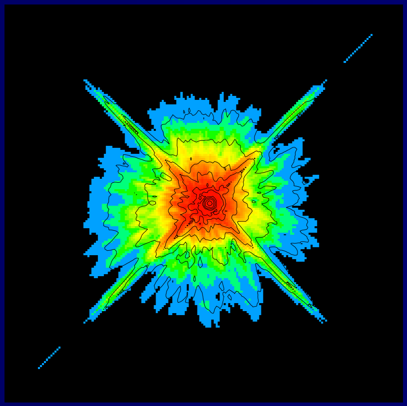
$1.221 \leq z \leq 1.895$

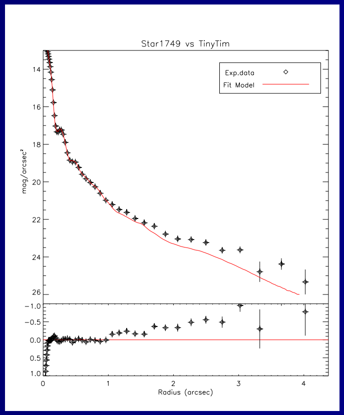
15 objects analyzed

- 13 resolved
- 1 marginally resolved

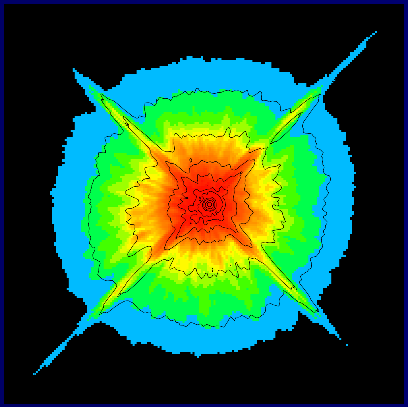
Kotilainen et al., ApJ, Vol.660

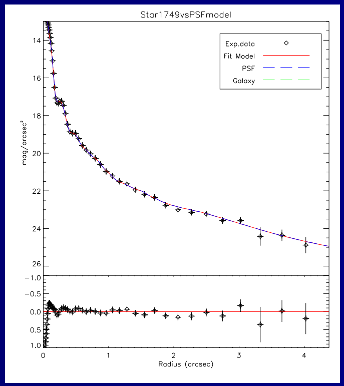
HST/WFPC2: PSF





TinyTim PSF



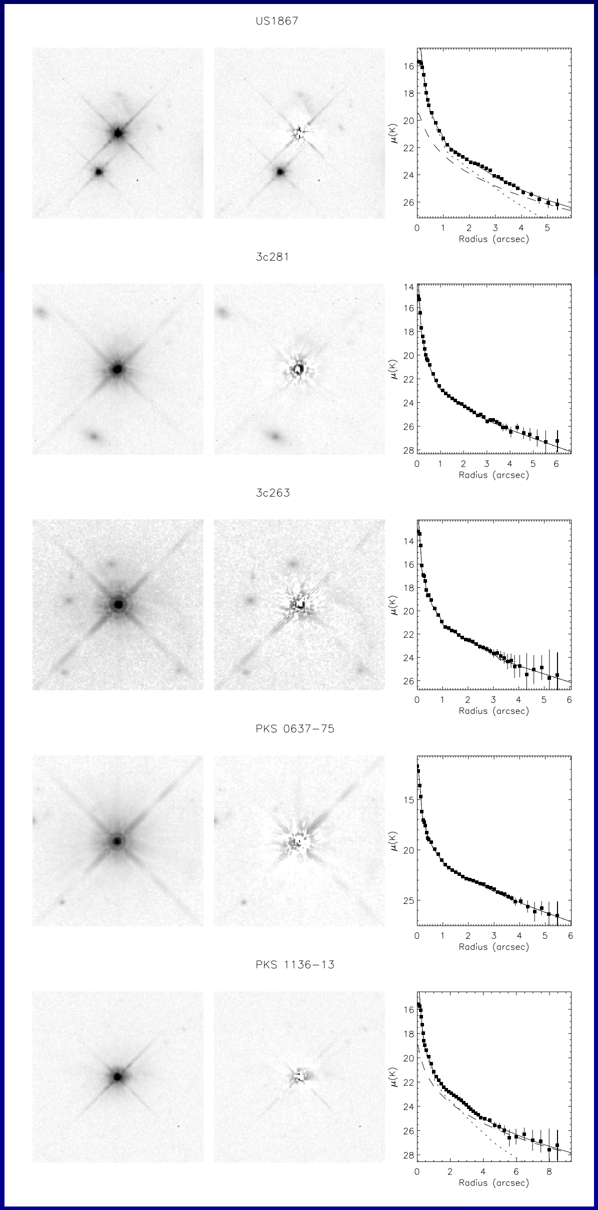


Mixed PSF model: empirical in the inner part (-> TinyTim generated); empirical+analytical (3 exp. Components) in the wings

HST/WFPC2 results

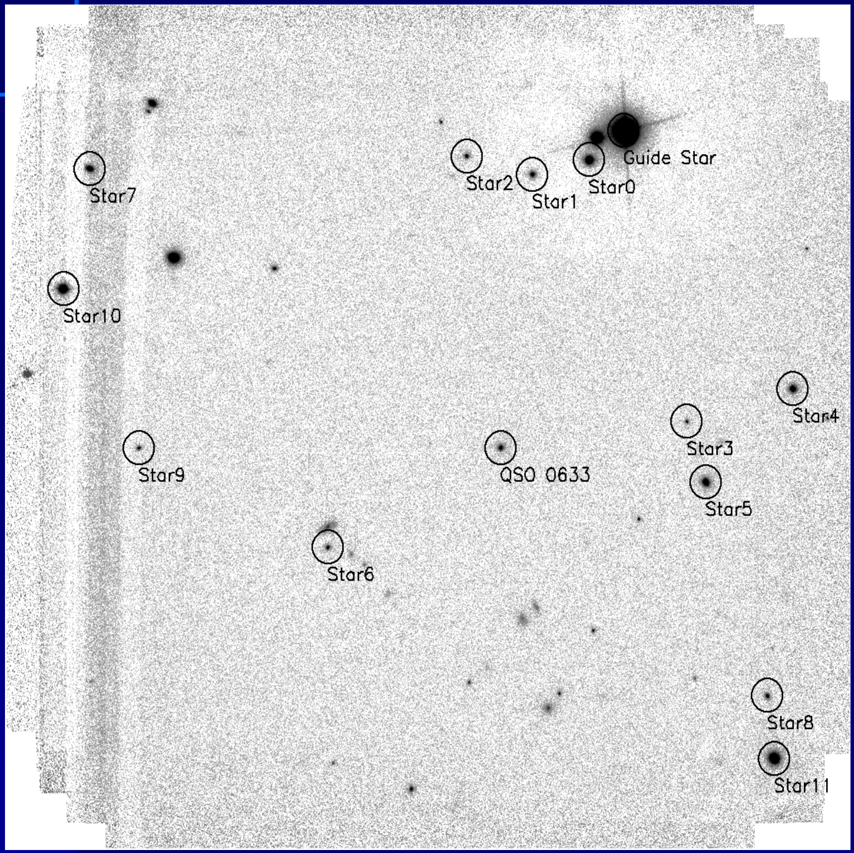
Images available in the HST archive (with WF3 or PC1), for 5 objects with no previous measurement of the host galaxy magnitude and morphology

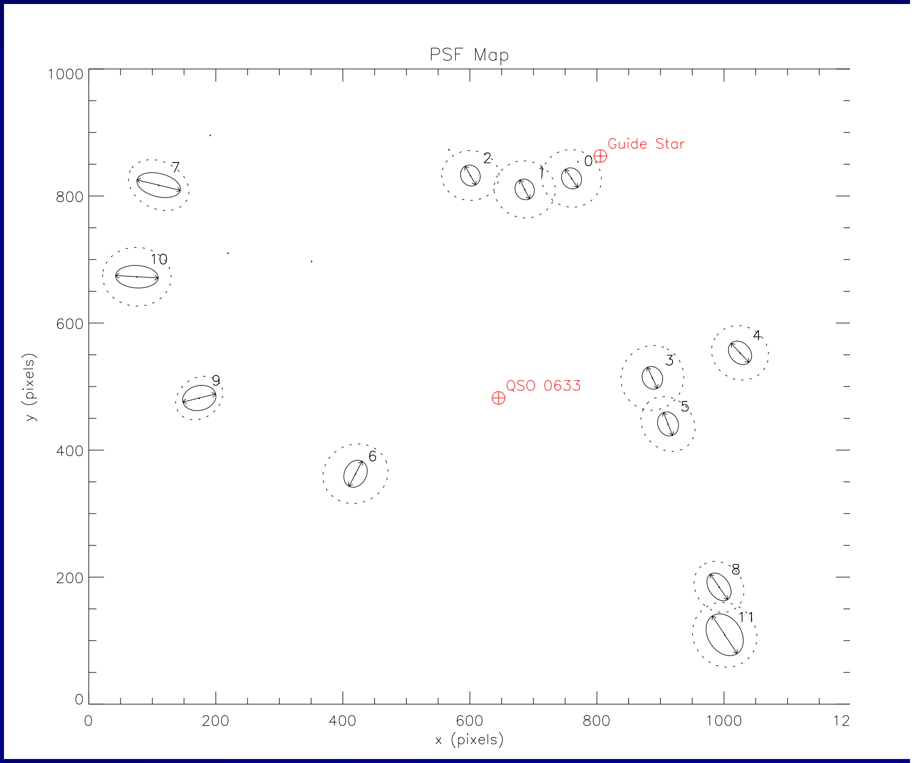
2 objects resolved



Labita et al., MNRAS, 373

VLT/NACO





PSF strongly variable in the FOV

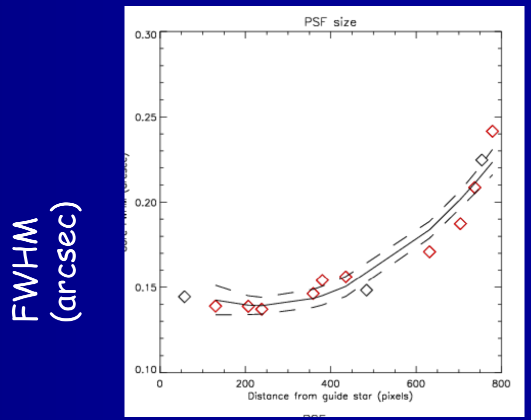
VLT/NACO

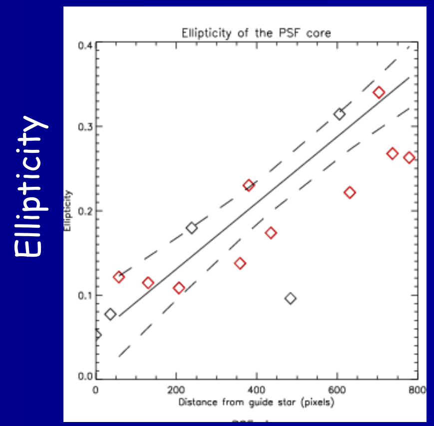
Analytical model with few parameters

↓

Dependence on the relative position respect of the guide star clearly show up

A more detailed model has been obtained using stars at the same distance from the GS as the object, then rotated to obtain the correct orientation





VLT/NACO

WGA J0633.1-2333 (z=2.928)

M_k=-27.1

R_e=6.5 kpc

(H=70, Ω_m=0.3, Ω_Λ=0.7)

Falomo et al., ApJ, 673 (2008)