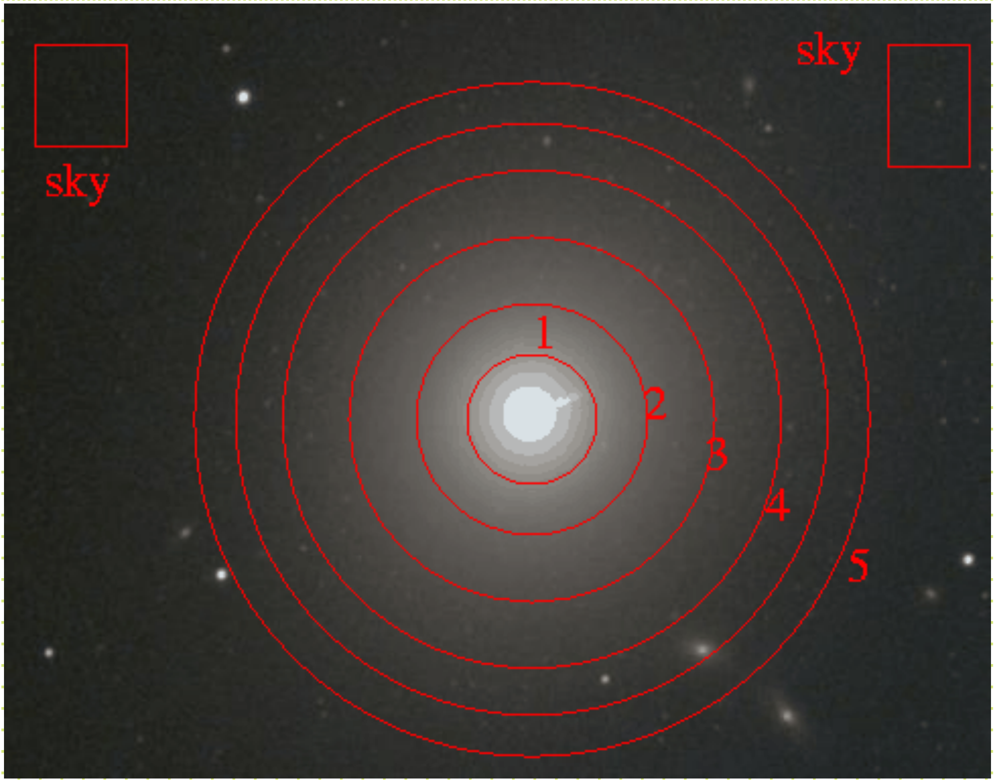
IRAF tricks

- DS9/ximtool save as option -- .eps file for inclusion into latex document.
  - Note sample .tex document at class www site
- In IRAF graphics window: *:.snap eps* will output a postscript file of whatever you have displayed
- hselect > filename will output hselect result to a text file

Surface Photometry

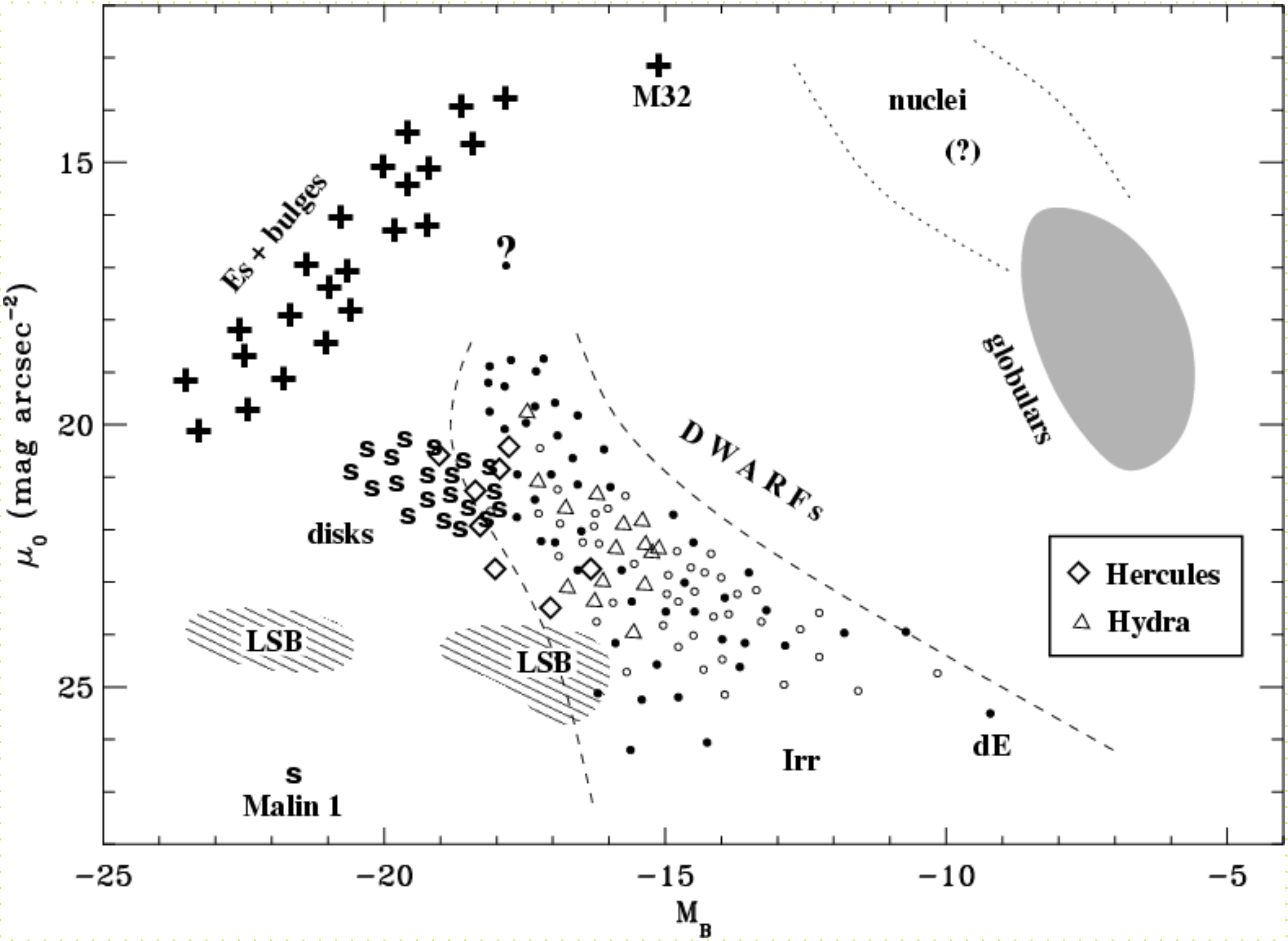


Simple approach of aperture photometry works OK for some purposes. For aperture radius r

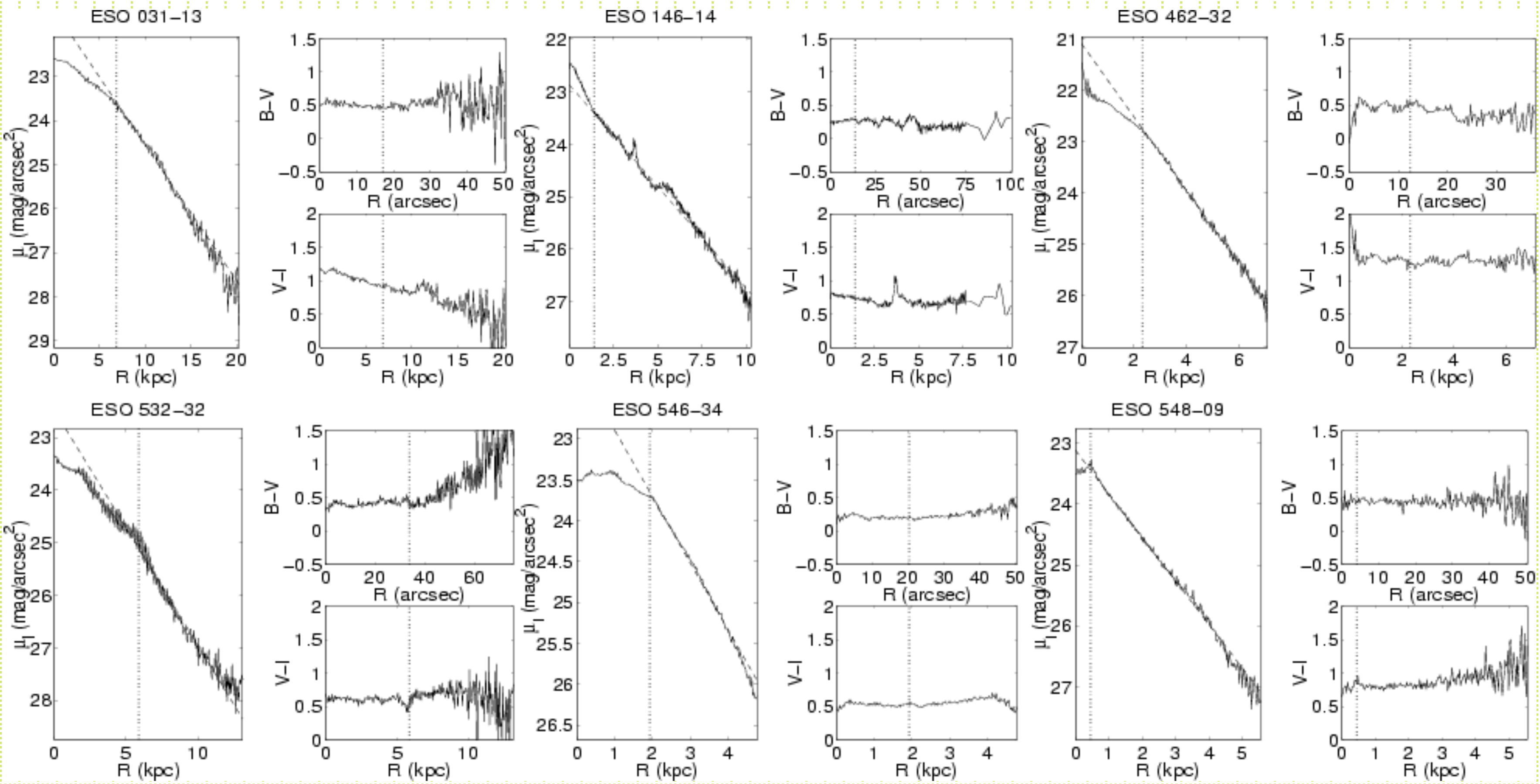
$$mag = c_0 - 2.5\log(\text{total cnts}_{aper} - \pi r^2 \text{sky})$$

Typically working with much larger apertures for galaxies

- prone to contamination
- sky determination even more critical
- often want to know more than total brightness



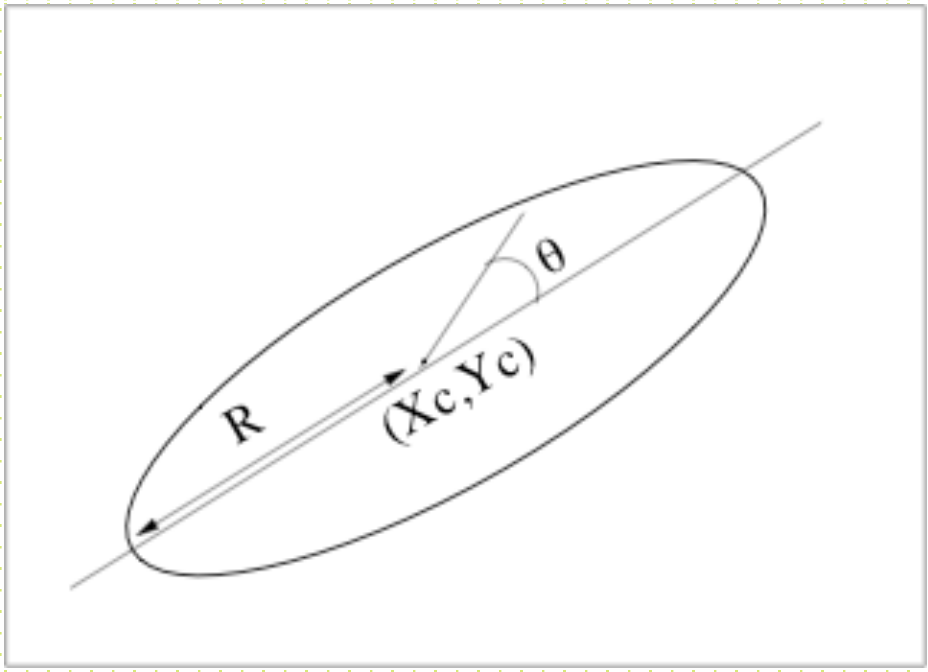
M32
nuclei
(?)
Es + bulges
?
globulars
DWARFs
disks
LSB
LSB
Hercules
Hydra
Irr
dE
s
Malin 1
15
20
25
−25
−20
−15
−10
−5
μ_0 (mag arcsec^{-2})
M_B



ESO 031−13
ESO 146−14
ESO 462−32
ESO 532−32
ESO 546−34
ESO 548−09
μ_I (mag/arcsec^2)
B−V
V−I
R (arcsec)
R (kpc)

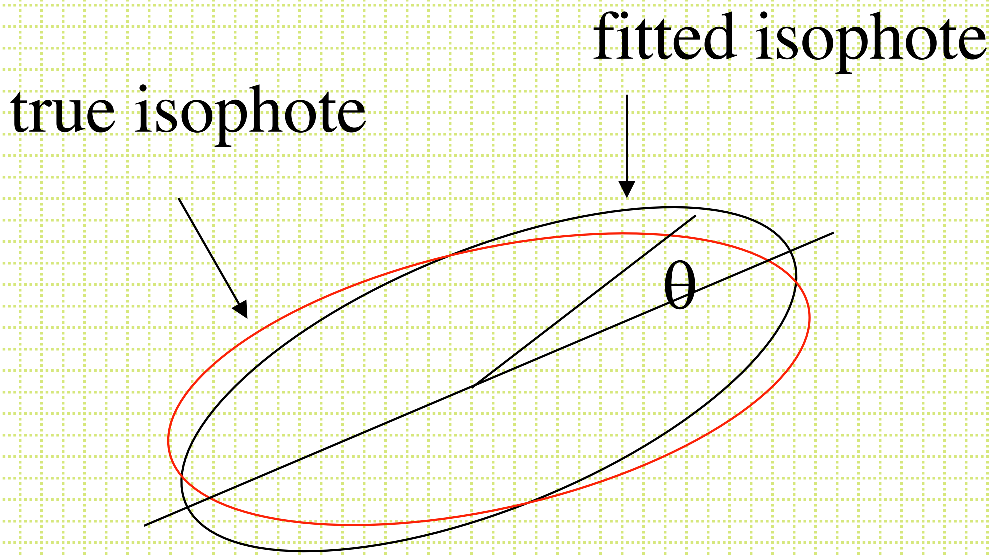
- There is a long history of surface photometry with CCDs:
  - GASP Davis et al., AJ, 90, 1985
  - Jedrzejewski, MNRAS, 226, 747, 1987 (Ellipse:STSci)
  - Ciambur B. C., 2015, ApJ, 810, 120 (update of Ellipse)
  - Erwin P., 2015, ApJ, 799, 226 (IMFIT)
  - GIM2D (Simard, 2002 ApJS 142, 1)
- Circular aperture photometry makes less sense as there are many different intrinsic shapes
- Most work is done with galaxy profile modeling

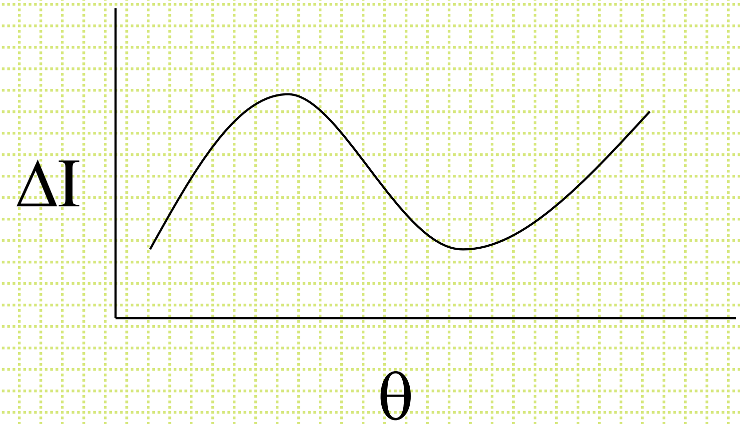
- Could fit (or find) *isophotes*, and the most common procedure is to fit elliptical isophotes.
- Parameters are: x_{center}, y_{center}, ellipticity (ε), R (semi-major axis) and position angle.



Start with guesses for x_c, y_c, R, ε and p.a., then compare the ellipse with real data all along the ellipse (all θ values)

Good isophote





Fit the ΔI - θ plot and iterate on x_c, y_c, p.a., and ε to minimize the coefficients in an expression like:

$$I(\theta)= I_0 + A_1\sin(\theta) + B_1\cos(\theta) + A_2\sin(2\theta) + B_2\cos(2\theta)$$

Changes to x_c and y_c mostly affect A_1, B_1,
p.a. " " A_2
ε " " B_2

- More specifically:

$$\Delta(\text{major axis center}) = \frac{-B_1}{I'}$$

$$\Delta(\text{minor axis center}) = \frac{-A_1(1-\varepsilon)}{I'}$$

$$\Delta(\varepsilon) = \frac{-2B_2(1-\varepsilon)}{a_0 I'}$$

$$\Delta(\text{p.a}) = \frac{2A_2(1-\varepsilon)}{a_0 I'[(1-\varepsilon)^2 - 1]}$$

where:

$$I' = \left.\frac{\partial I}{\partial R}\right|_{a_0}$$

← Position along the semi-major axis

- After finding the best-fitting elliptical isophotes, the residuals are often interesting. Fit:

$$I = I_0 + A_n \sin(n\theta) + B_n \cos(n\theta)$$

already minimized n=1 and n=2, n=3 is usually not significant, but:

B_4 is negative for ``Boxy'' isophotes

B_4 positive for ``disky'' isophotes

Surface Photometry Tools

- How do you carry out surface photometry measurements?
- For the class will use a Jedrxxxx-based set of algorithms available via IRAF in the STScI STSDAS set of packages.
- stsdas.analysis.isophote

Stsdas isophote tasks

bmodel	geompar@	isomap	magpar@
controlpar@	isoexam	isopall	samplepar@
ellipse	isoimap	isoplot	

Parameter files

Controlpar

```
PACKAGE = isophote
   TASK = controlpar

(conver =              0.05) convergency criterion (maximum harmonic amplitud
(minit  =                10) minimun no. of iterations at each sma
(maxit  =                50) maximun no. of iterations at each sma
(hcenter=                no) hold center fixed ?
(hellip =                no) hold ellipticity fixed ?
(hpa    =                no) hold position angle fixed ?
(wander =             INDEF) maximum wander in successive isophote centers
(maxgerr=               0.5) maximum acceptable gradient relative error
(olthres=                1.) object locator's k-sigma threshold
(soft   =                no) soft stop ?
(mode   =                al)
```

Geompar

PACKAGE = isophote
TASK = geompar

(x0 =	INDEF)	initial isophote center X
(y0 =	INDEF)	initial isophote center Y
(ellip0 =	0.2)	initial ellipticity
(pa0 =	20.)	initial position angle (degrees)
(sma0 =	10.)	initial semi-major axis lenght
(minsma =	0.)	minimum semi-major axis lenght
(maxsma =	INDEF)	maximum semi-major axis lenght
(step =	0.1)	sma step between successive ellipses
(linear =	no)	linear sma step ?
(maxrit =	INDEF)	maximum sma lenght for iterative mode
(recente=	yes)	allows finding routine to re-center x0-y0 ?
(xylearn=	yes)	updates pset with new x0-y0 ?
(physica=	yes)	physical coordinate system ?

Often it is a good idea to put in starting values

Samplepar

PACKAGE = isophote
TASK = samplepar

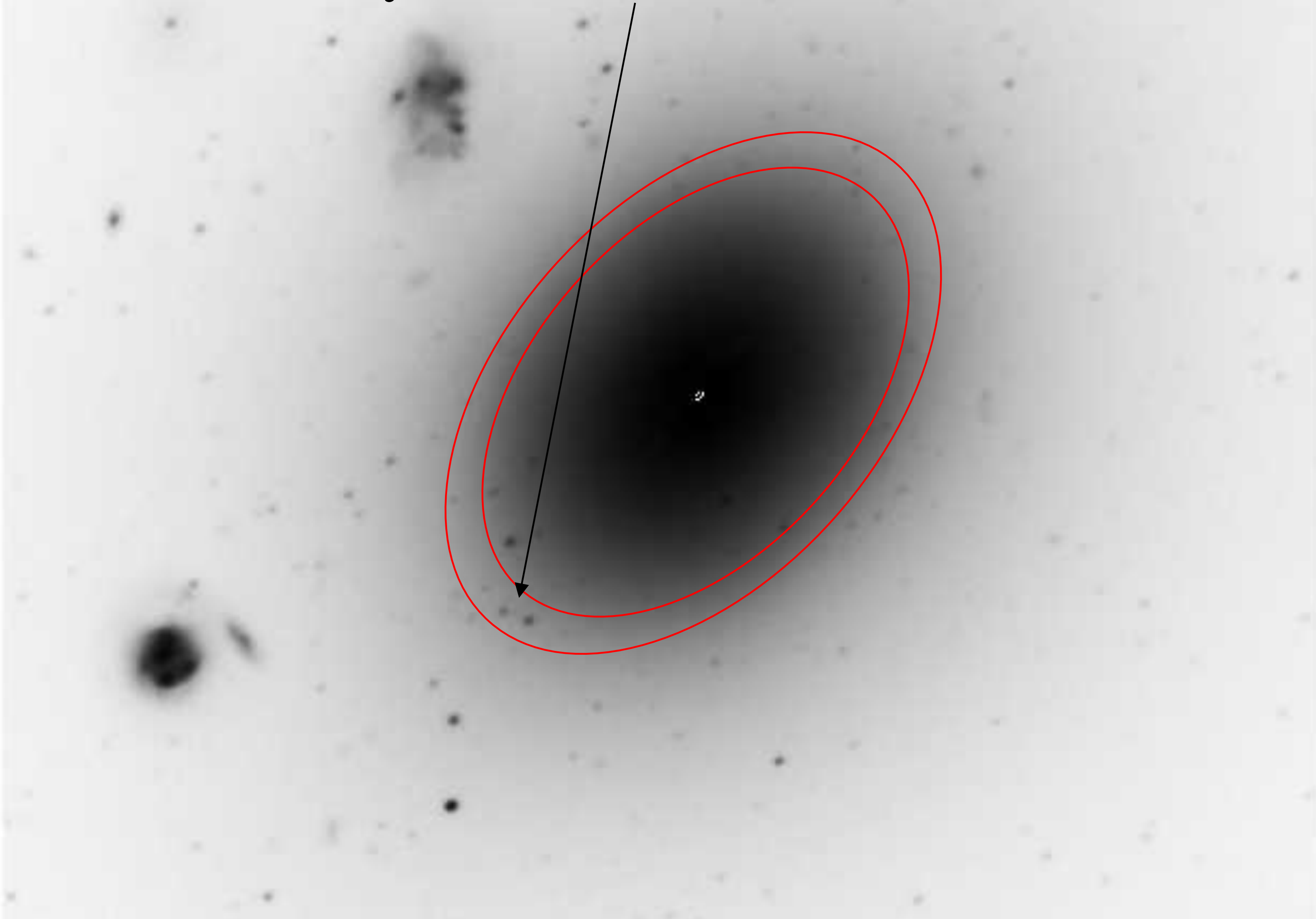
(integrm= bi-linear) area integration mode
(usclip = 3.) sigma-clip criterion for upper deviant points
(lsclip = 3.) sigma-clip criterion for lower deviant points
(nclip = 0) number of sigma-clip iterations
(fflag = 0.5) acceptable fraction of flagged data points
(sdevice= none) graphics device for ploting intensity samples
(tsample= none) tables with intensity samples
(absangl= yes) sample angles refer to image coord. system ?
(harmoni= none) optional harmonic numbers to fit
(mode = al)

Important!

ellipse

- Use the σ-clipping option
  - Very common to pre-clean frames:
    - Subtract point sources with DAOPHOT
    - Mask saturated stars and CCD flaws
    - Mask other galaxies
- Sometimes it is useful to input starting values

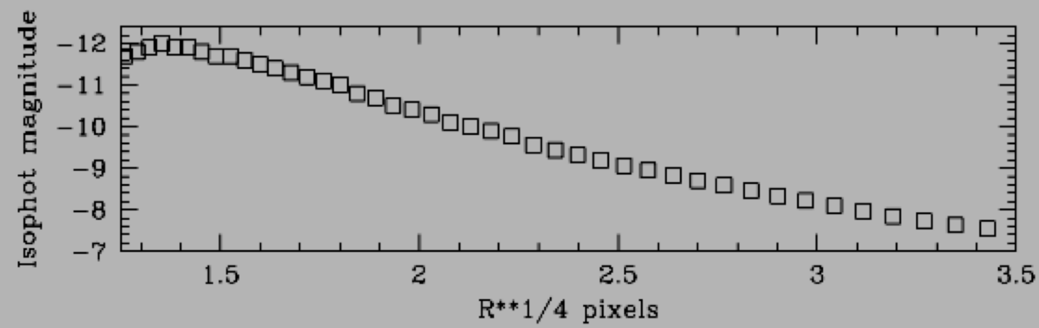
Calculate mean and RMS pixel intensity for annulus, toss any values above <u>mean + nRMS</u>

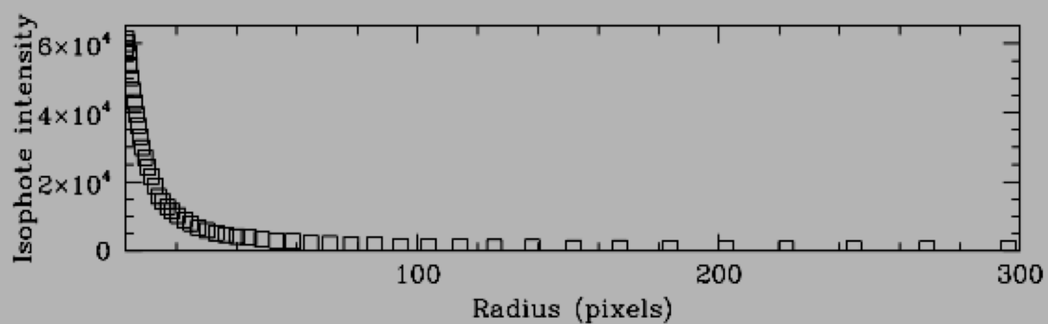


- Ellipse produces a Table (in STSDAS table format, ttools.tprint allows you to view this) with the parameters of the best fitting ellipses along the semi-major axis.
- Plotting $I_{ellipse}$ vs r gives the *surface brightness profile*

Photometry is the usual:

$$m=c_0 - 2.5\log(\Sigma(\text{pixels in } r+\Delta r) - (\text{npix} \bullet \text{sky})$$

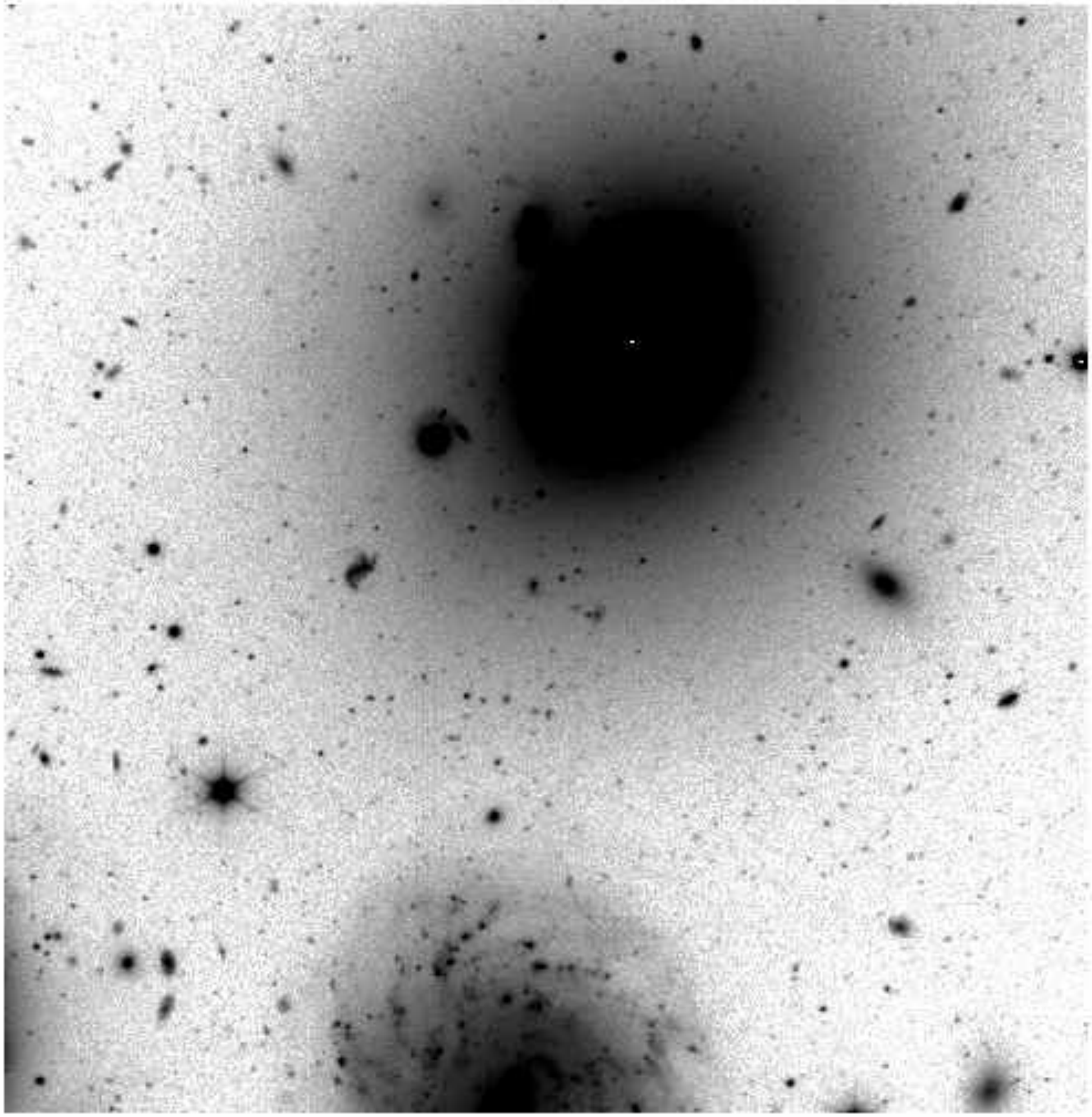

Isophot magnitude
-12
-11
-10
-9
-8
-7
1.5
2
2.5
3
3.5
R**1/4 pixels

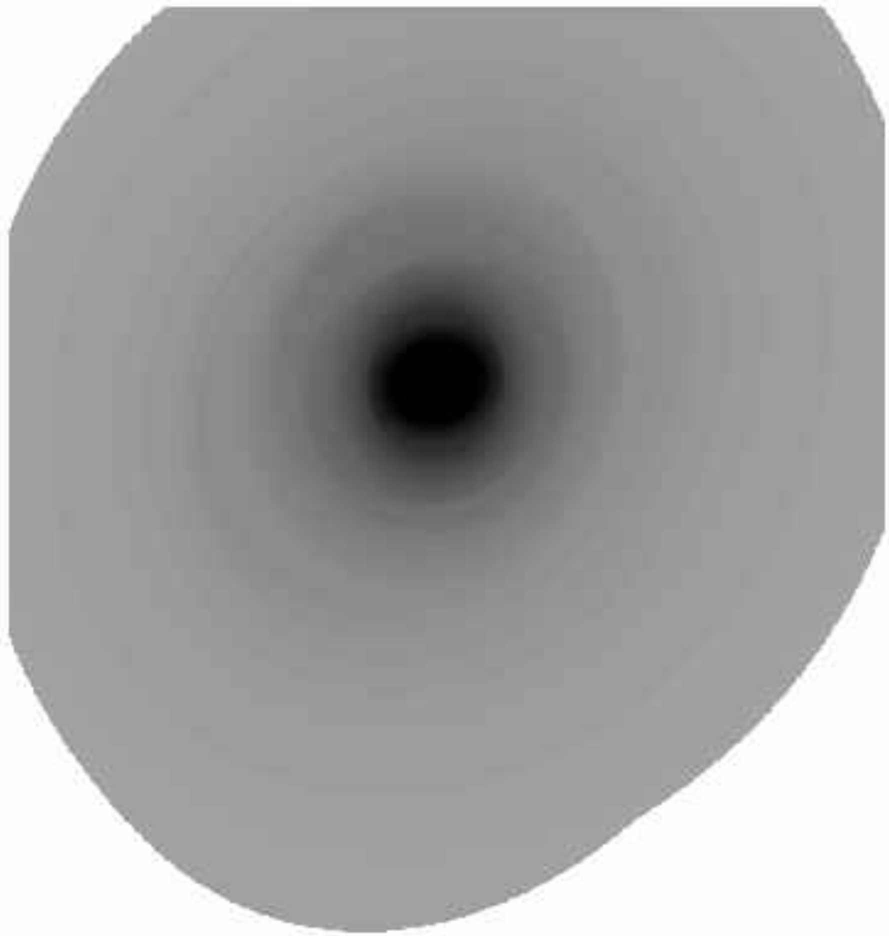

Isophote intensity
6×10⁴
4×10⁴
2×10⁴
0
100
200
300
Radius (pixels)

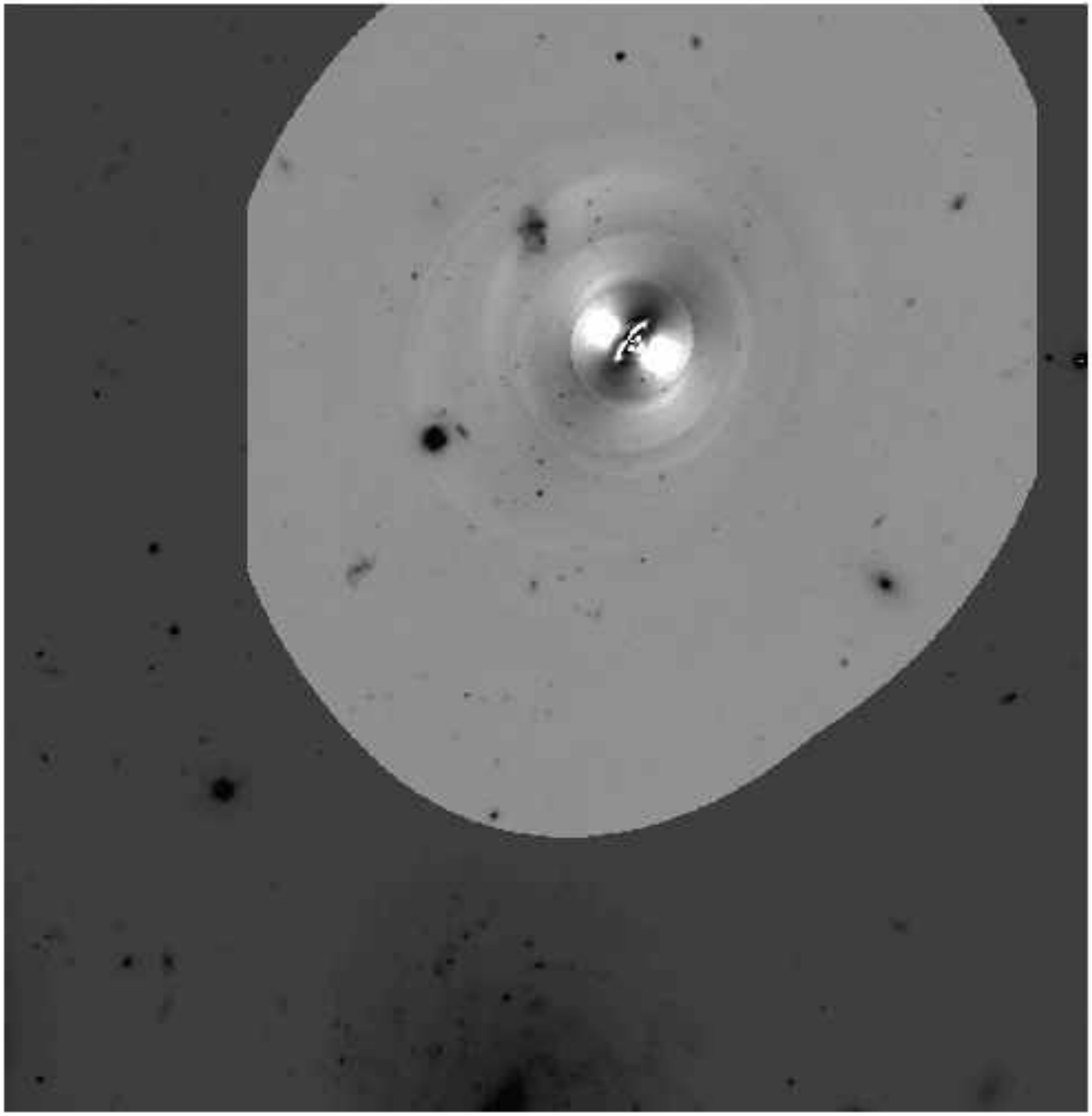
```
input image name (test3):
output table name (test3.tab):
Running object locator... Done.
#
# Semi-    Isophote      Ellipticity     Position   Grad.  Data Flag Iter. Stop
# major      mean                          Angle      rel.               code
# axis     intensity                                 error
#(pixel)                               (degree)
#
  40.00  4219.62(527.26) 0.123(0.002) -70.00( 0.54) 0.125  234   0    50    2
  44.00  3773.10(481.03) 0.123(0.002) -70.00( 0.59) 0.122  258   0    50    2
  48.40  3384.59(426.91) 0.123(0.002) -70.00( 0.52) 0.116  284   0    50    2
  53.24  3038.81(384.52) 0.123(0.002) -70.00( 0.47) 0.110  312   0    50    2
  58.56  2725.05(344.36) 0.123(0.002) -70.00( 0.56) 0.097  343   0    50    2
  64.42  2431.91(297.83) 0.123(0.002) -70.00( 0.38) 0.091  378   0    50    2

634.52   556.57(  7.44) 0.273(0.009) -18.68( 1.03) 0.101 2602 760    17    1
  36.36  4728.37(566.24) 0.123(0.003) -70.00( 0.70) 0.125  213   0    50    2
  33.06  5287.32(620.80) 0.123(0.005) -70.00( 1.36) 0.129  193   0    50    2


   0.73 51976.14(8482.2) 0.269(INDEF) -45.76(INDEF) 1.460   13   0     1    4

   0.66 53679.33(7585.3) 0.269(INDEF) -45.76(INDEF) 1.853   13   0     1    4
   0.60 55147.36(7006.2) 0.269(INDEF) -45.76(INDEF) 1.951   13   0     1    4
   0.55 56150.06(6355.0) 0.269(INDEF) -45.76(INDEF) 2.616   13   0     1    4
```

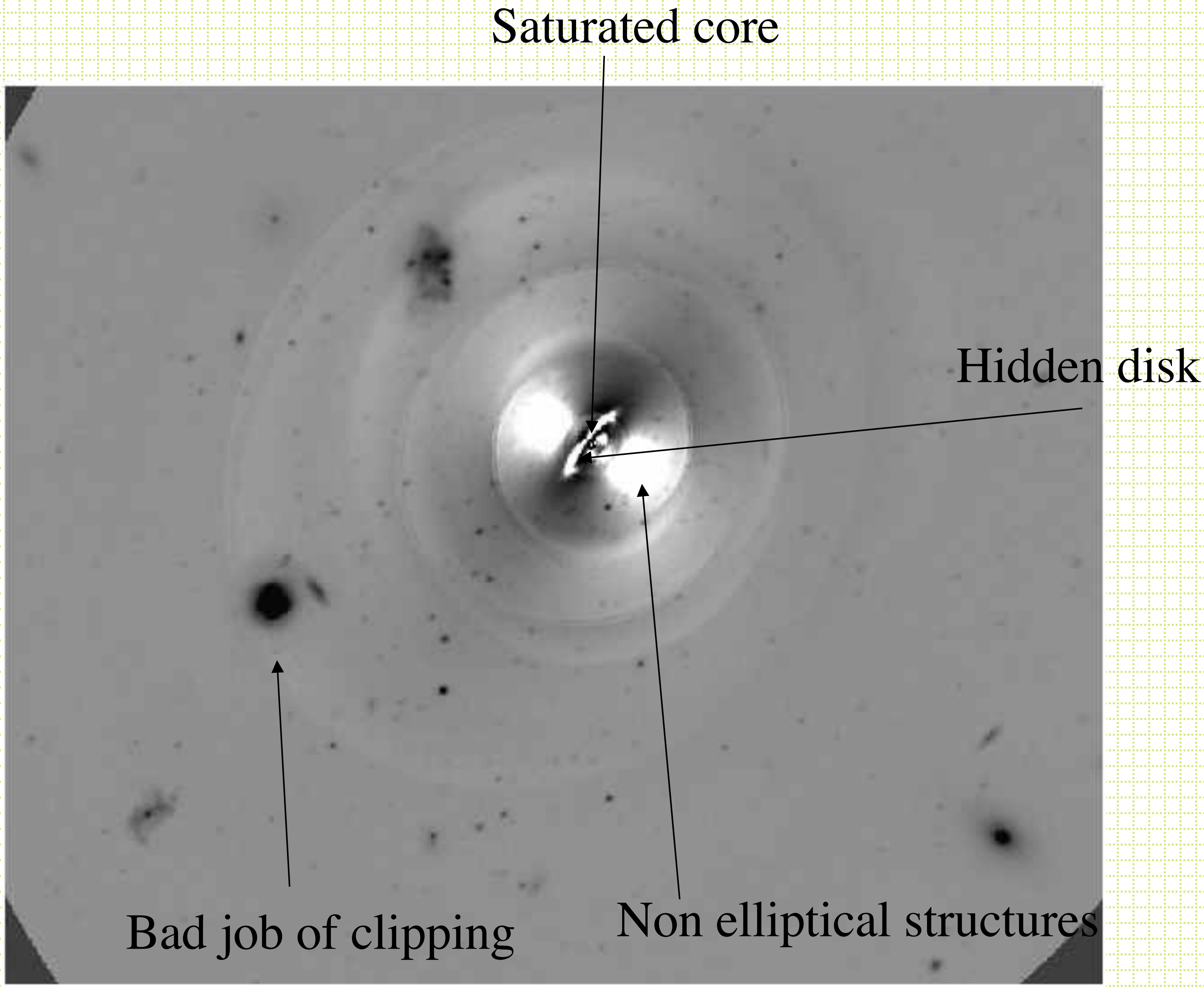
bmodel

- After you have run ellipse and produced a table. The task called *bmodel* will build a smooth image of the family of ellipses. Subtracting this from the original frame will tell you how good the fit is and will reveal non-axially symetric structures.

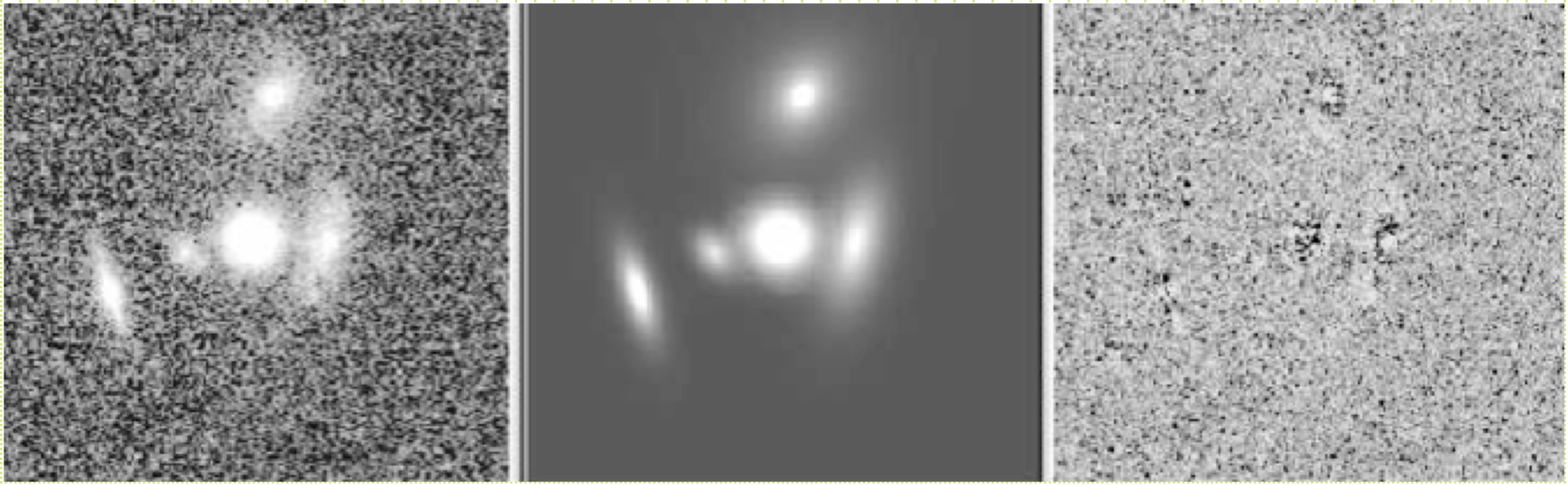







Saturated core
Hidden disk
Bad job of clipping
Non elliptical structures

GALFIT, GIM2D

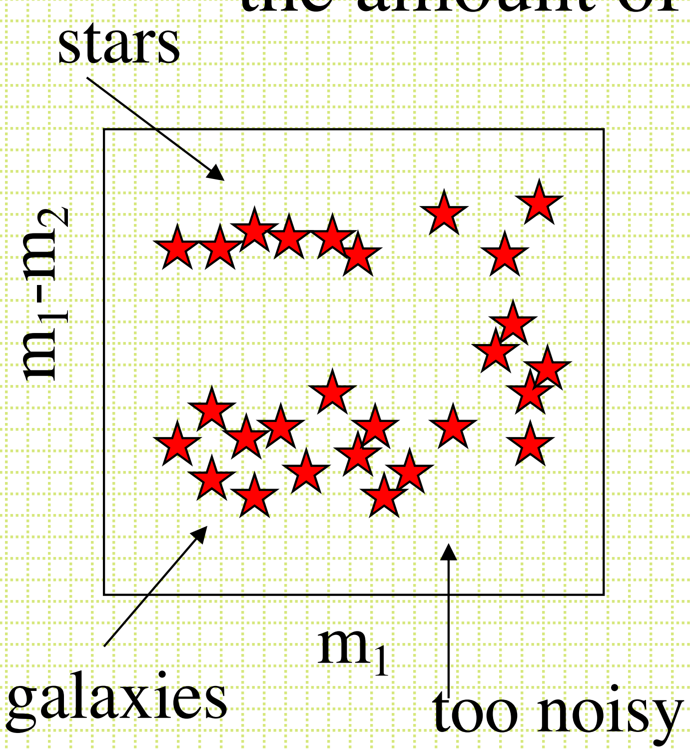


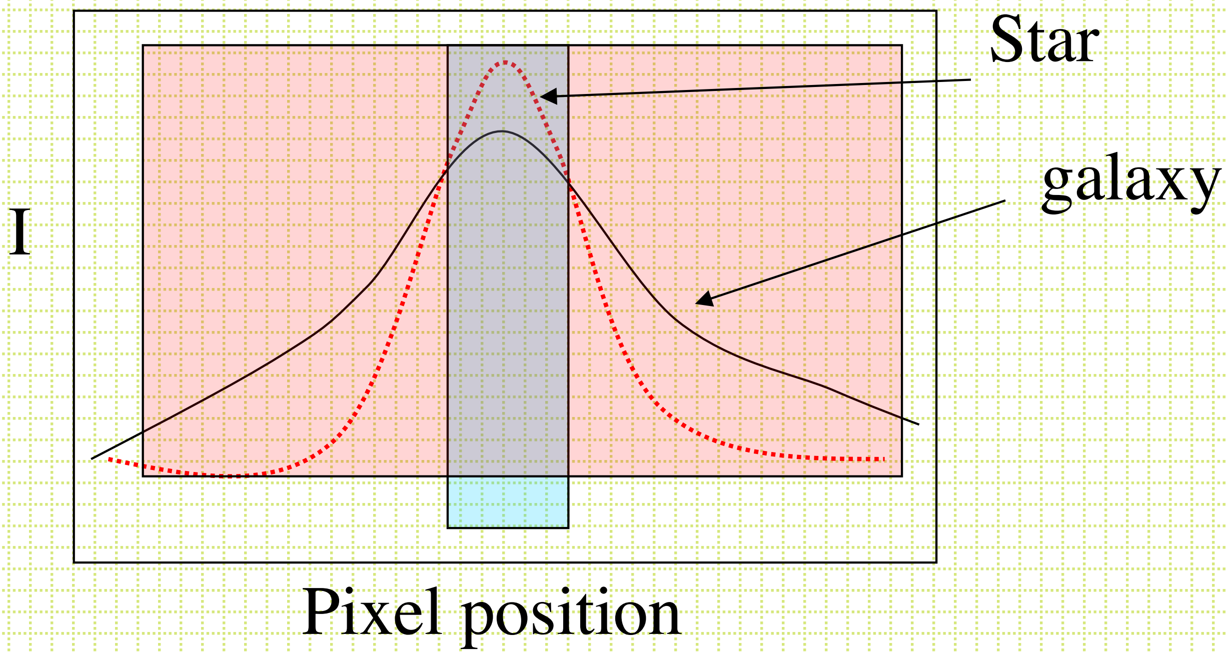
Small galaxies and classification

- Originally (starting with Kron in 1979) simple star-galaxy separation was the goal.
- These days packages do a lot more:
  - Deblending
  - Filtering
  - Photometry shape decomposition
    - FOCAS Jarvis & Tyson, 1981, AJ 86, 476
    - PPP Yee, 1991, PASP, 103 396
    - Sextractor Bertin & Arnouts, 1996, A&A Sup. Ser. 117,393

Star-Galaxy separation

- Galaxies are resolved, stars are not
- All methods use various approaches to comparing the amount of light at large and small radii.





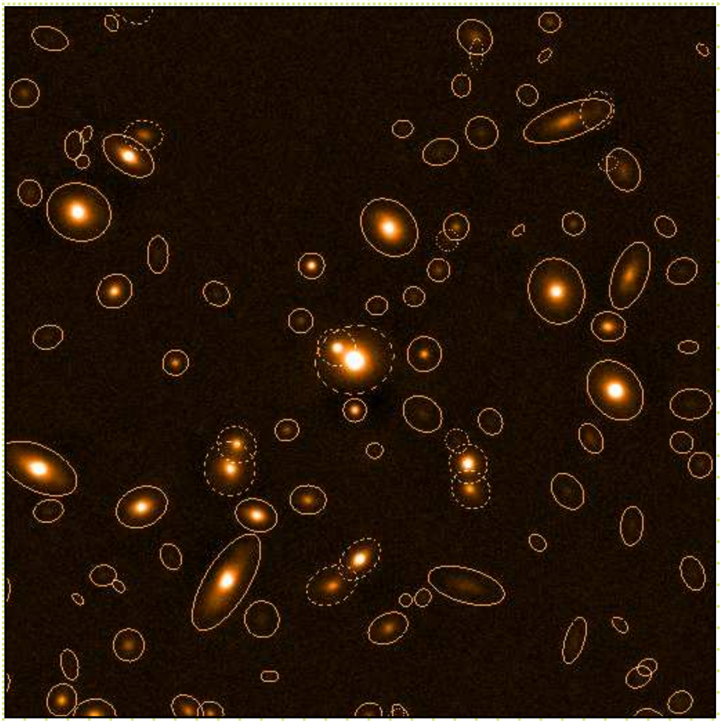
- $m_{\text{small r}}/m_{\text{large r}}$
- Total mag/peak count
- Mag/average surface brightness
- DAOPHOT CHI (PSF fit/predicted PSF fit)
- petroR50/petroR90 (SDSS)
- Often talk about *moment analysis*.

$$\frac{\sum_i I_i x_i^n}{\sum_i I_i}$$

Same thing in y. n=1 is centroid, n=2 is variance etc.

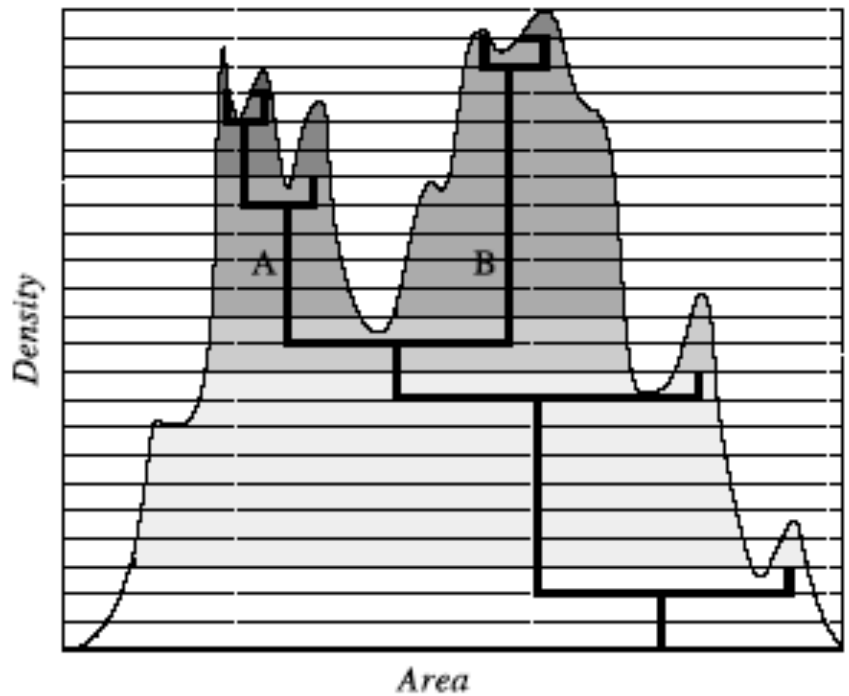
Note; ratio of second moments useful for ellipticity measurements

Sextractor



- Most commonly used package these days is SExtractor (although for pure star-galaxy separation it is hard to beat using the difference of two apertures).

- Bertin & Arnouts, 1996, A&AS, 117, 393
- User’ s Manual
- Sextractor for Dummies v4
- Not for good surface photometry, but good for classification and rough photometric and structural parameter derivation for large fields.
    1. Background map (sky determination)
    2. Identification of objects (thresholding)
    3. Deblending
    4. Photometry
    5. Shape analysis



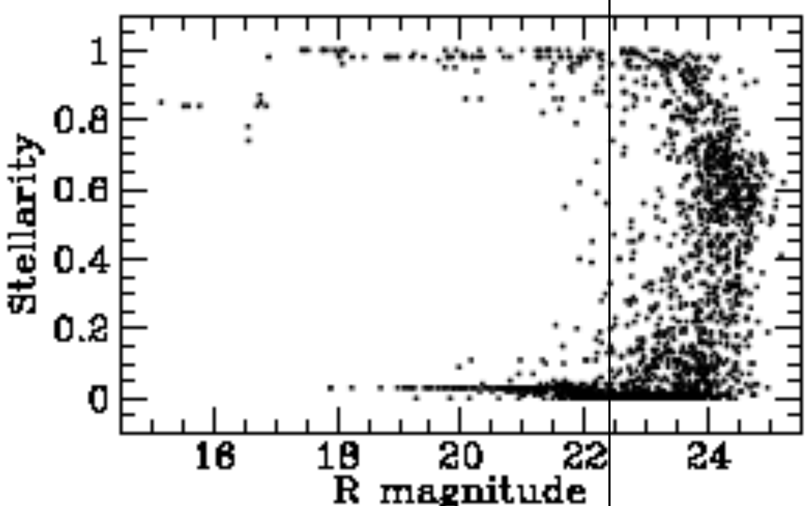
Thresholding is an alternative to *peak finding*. Look for contiguous pixels above a threshold value.

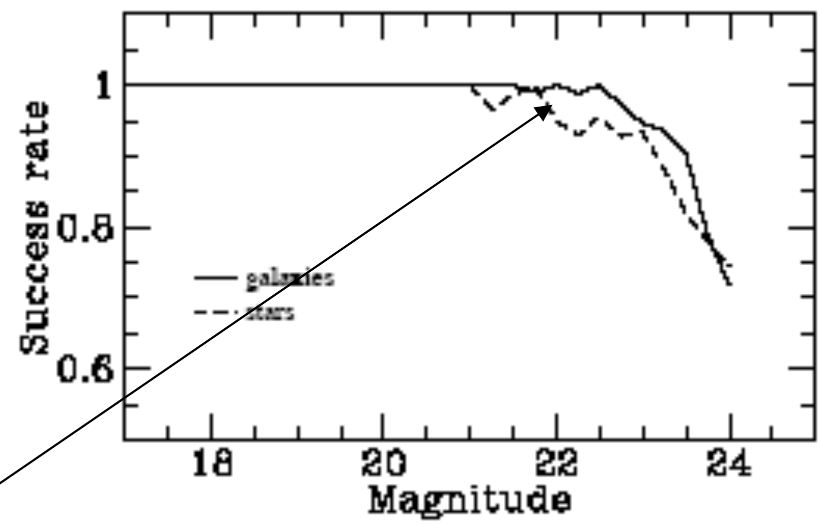
- User sets area, threshold value.
- Sometimes combine with a smoothing filter

Deblending based on multiple-pass thresholding

Sextractor Star/Galaxy Separation

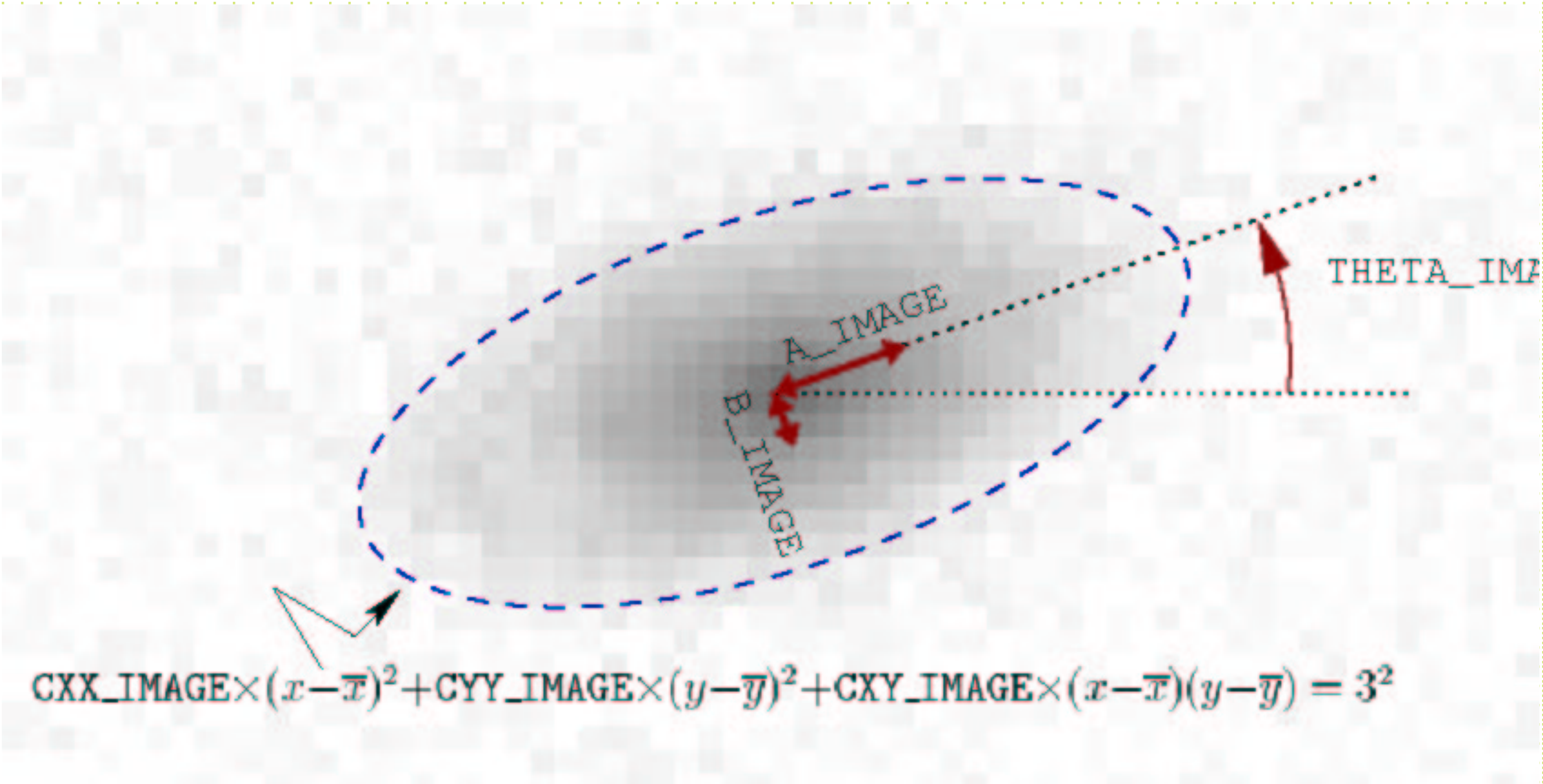
- Lots of talk about neural-net algorithms, but in the end it is a moment analysis.
- ``stellarity’’. Typically test it with artificial stars and find it is very good to some limiting magnitude.

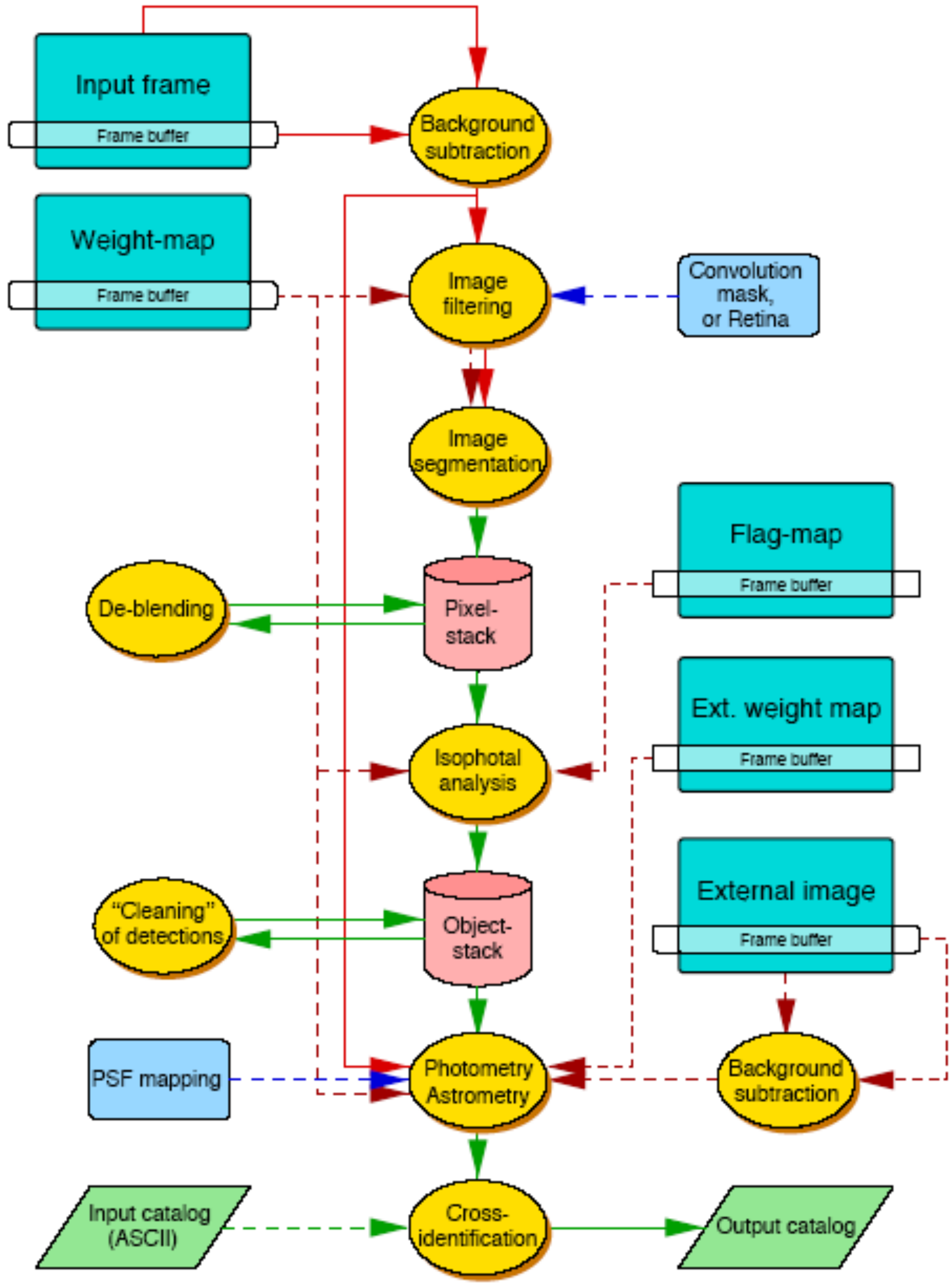




s-g going bad at R~22

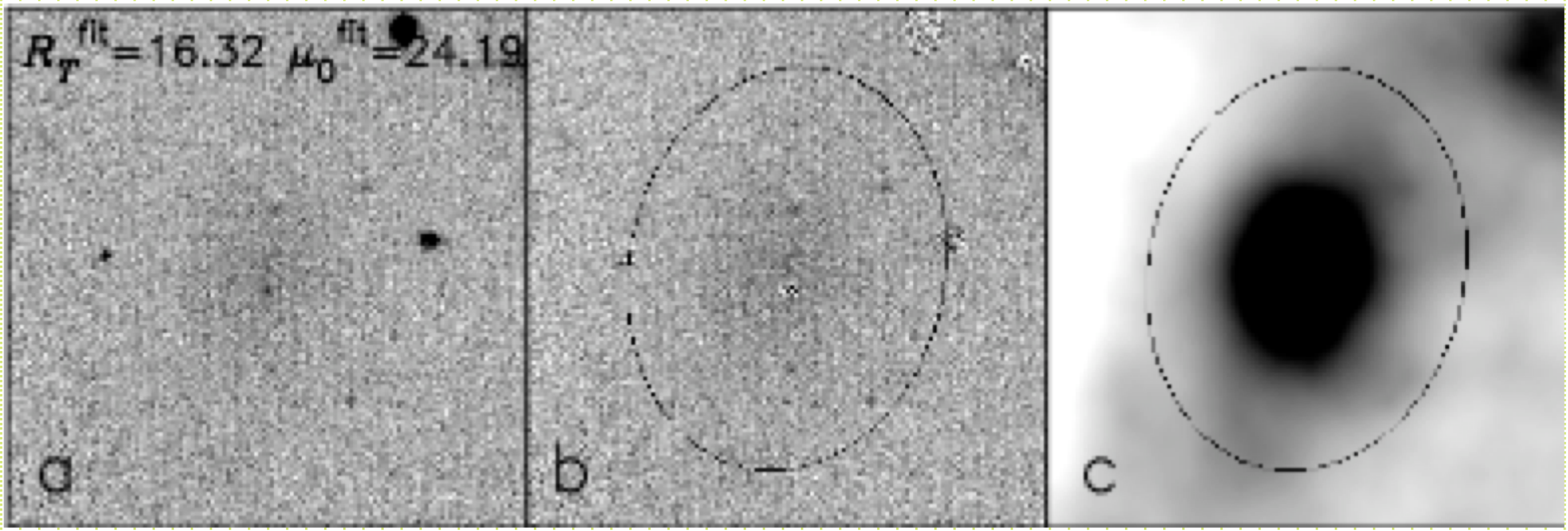
Shapes

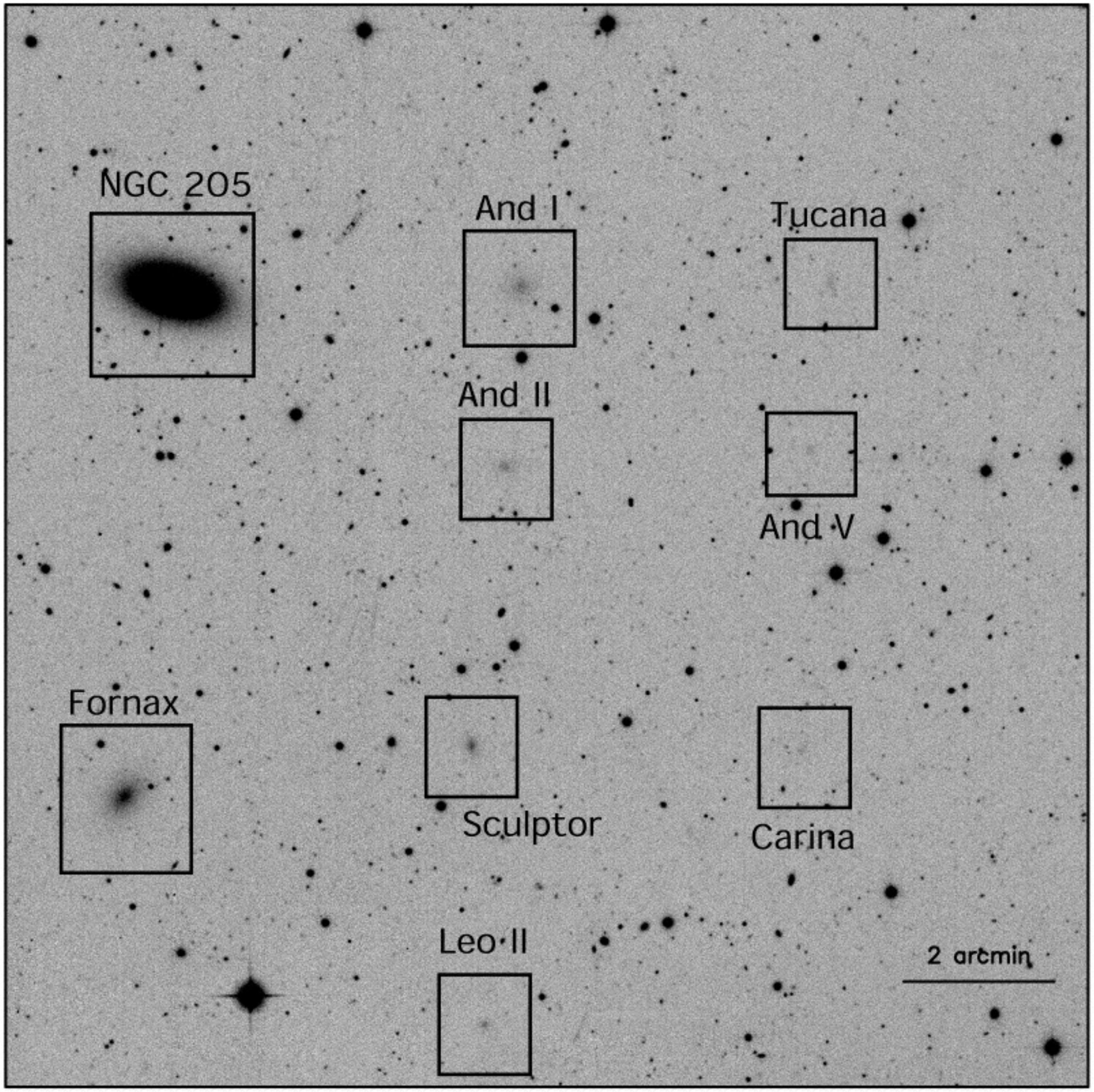

THETA_IMA
A_IMAGE
B_IMAGE
CXX_IMAGE×(x−x̄)²+CYY_IMAGE×(y−ȳ)²+CXY_IMAGE×(x−x̄)(y−ȳ) = 3²

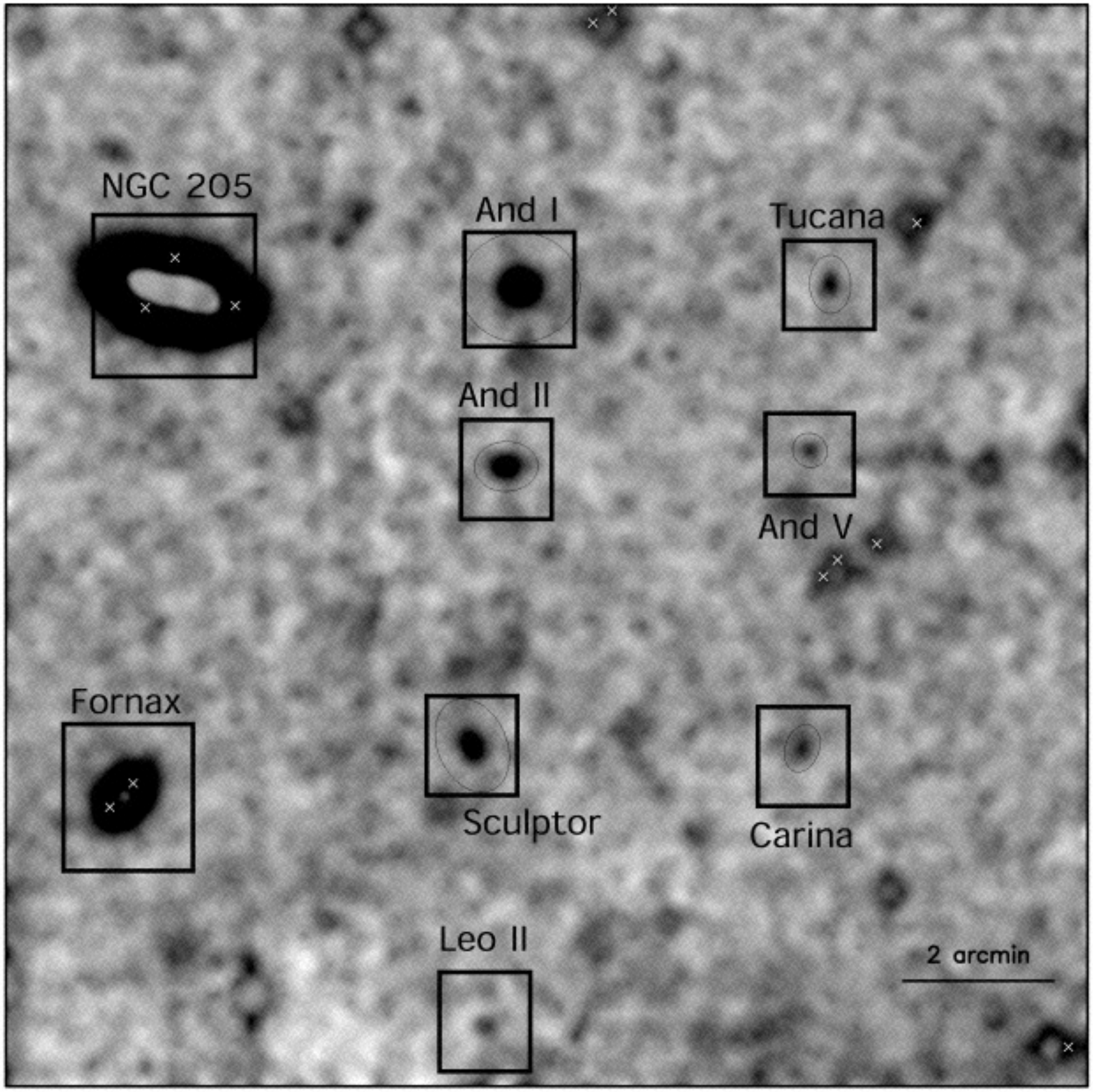


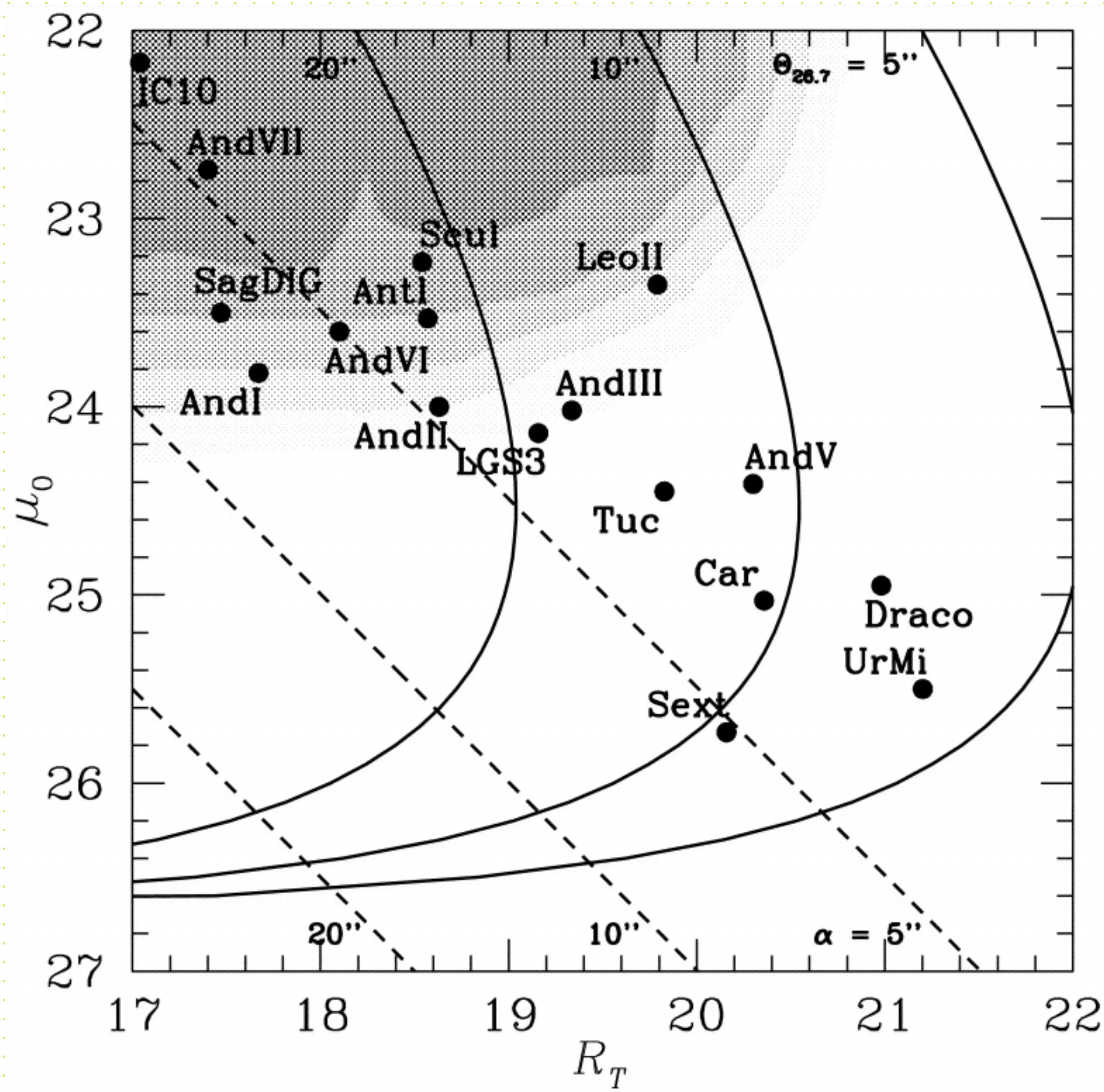
Input frame
Frame buffer
Background subtraction
Weight-map
Frame buffer
Image filtering
Convolution mask, or Retina
Image segmentation
Flag-map
Frame buffer
De-blending
Pixel-stack
Ext. weight map
Frame buffer
Isophotal analysis
"Cleaning" of detections
Object-stack
External image
Frame buffer
PSF mapping
Photometry Astrometry
Background subtraction
Input catalog (ASCII)
Cross-identification
Output catalog

Convolved image analysis

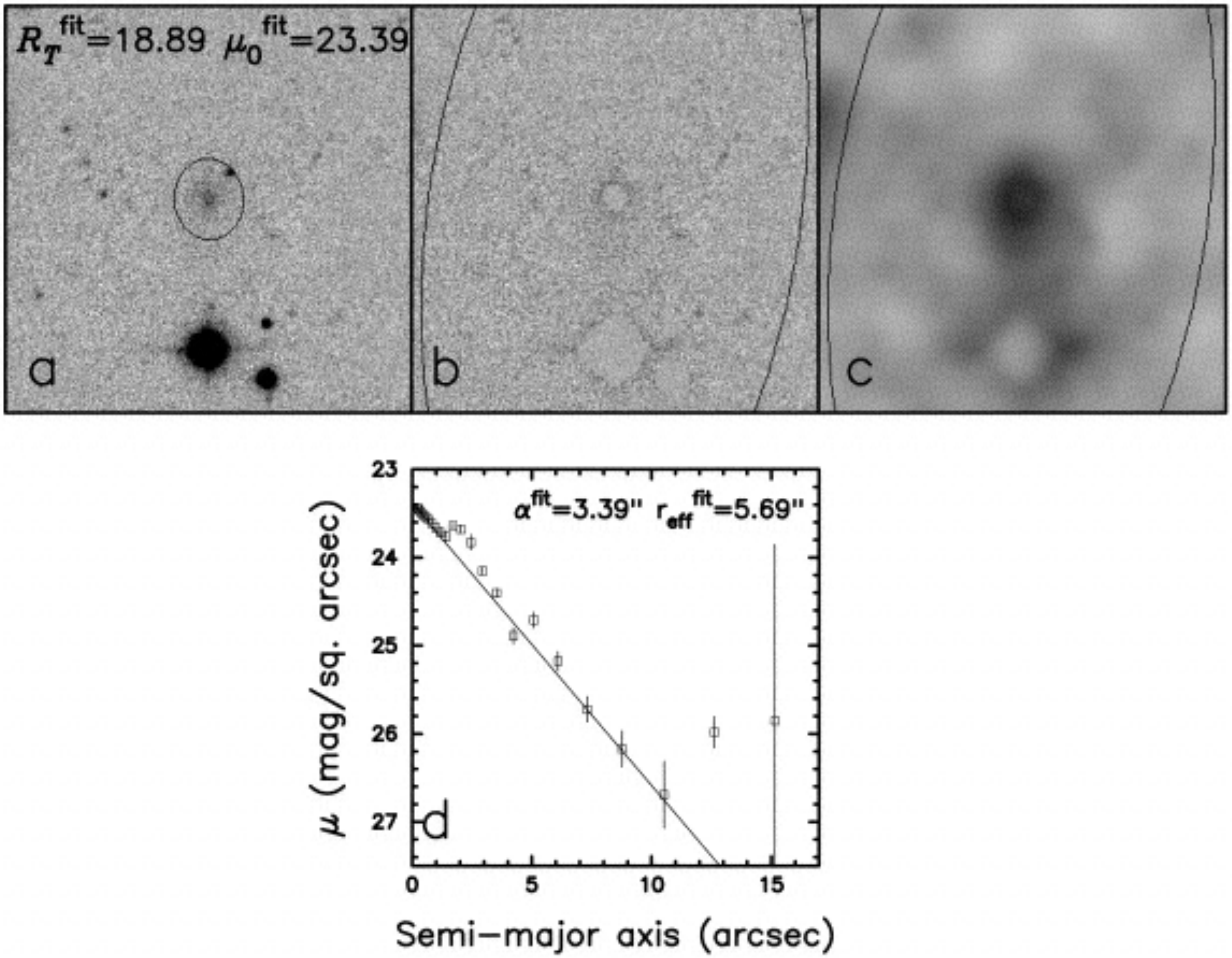



NGC 205
And I
Tucana
And II
And V
Fornax
Sculptor
Carina
Leo II
2 arcmin


NGC 205
And I
Tucana
And II
And V
Fornax
Sculptor
Carina
Leo II
2 arcmin



20''
10''
θ26.7 = 5''
IC10
AndVII
Scul
LeoII
SagDIG
AntI
AndVI
AndIII
AndI
AndII
LGS3
AndV
Tuc
Car
Draco
UrMi
Sext
20''
10''
α = 5''
22
23
24
25
26
27
17
18
19
20
21
22
μ0
RT



R_T^{fit}=18.89 μ_0^{fit}=23.39
a
b
c
d
α^{fit}=3.39'' r_{eff}^{fit}=5.69''
μ (mag/sq. arcsec)
Semi−major axis (arcsec)
23
24
25
26
27
0
5
10
15