Automatic Morphological Classification of Galaxies - Vera C. Rubin data

Zsolt Frei, Tamás Kovács
(Eötvös U.)

Plitvice; October 12, 2022

VERA C. RUBIN OBSERVATORY

ELTE EÖTVÖS LORÁND TUDOMÁNYEGYETEM

Outline:

- Eötvös U. vs Eötvös LKH
- Traditional morphological classification
- Quantitative classifiers, workflow
- A sample galaxy processed
- Applications
- Future tasks

Eötvös U. vs Eötvös LKH

Eötvös University

Institute of Physics

"Excellence" Program

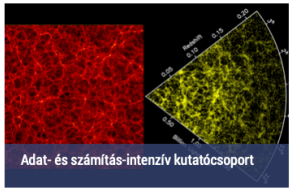
ELKH-ELTE Research Group

AZ ASZTROFIZIKA TERÜLETÉN MŰKÖDŐ KUTATÓCSOPORTJAINK


GALNUC ERC Starting Grant kutatócsoport


MTA-ELTE Extragalaktikus Asztrofizika Kutatócsoport


ELTE Gravitációshullám- és Kozmológiai Kutatócsoport


Adat- és számítás-intenzív kutatócsoport


Üridőjárás és űrklíma Kutatócsoport


Bolygórendszerek és eredetük kutatócsoport

A RÉSZECSKEFIZIKA TERÜLETÉN MŰKÖDŐ KUTATÓCSOPORTJAINK

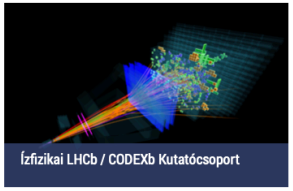

MTA-ELTE "Lendület" CMS Részecske- és Magfizikai Kutatócsoport


MTA-ELTE "Lendület" Rácstérelméleti Kutatócsoport


Részecskefizika Fenomenológia Kutatócsoport

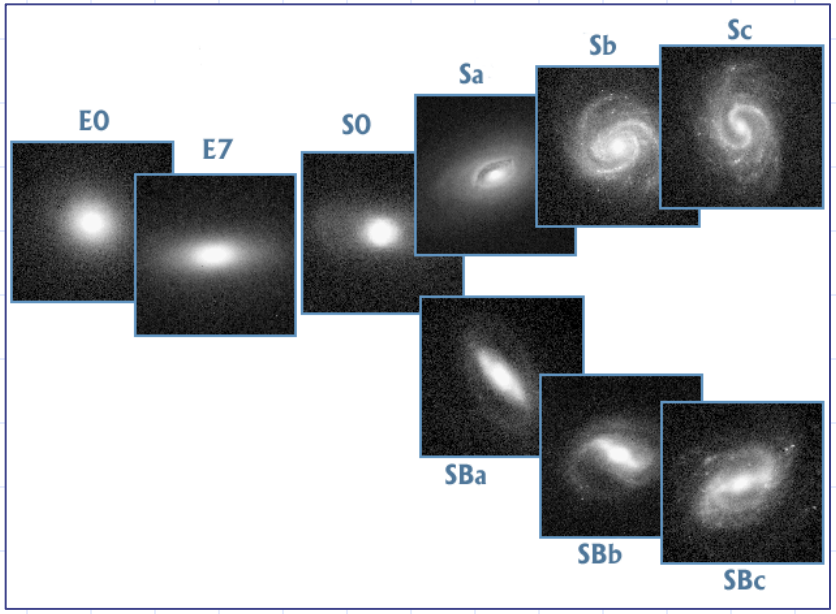

RHIC-Magyarország kutatócsoport


Kísérleti Neutrínó Fizikai Kutatócsoport


Ízfizikai LHCb / CODEXb Kutatócsoport

Details of the sequence:

Hubble's "tuning fork"



A. Ellipticals: E0-E7
B. Spirals: Sa-Sc:
   - Disk/bulge ratio changes
   - Opening angle changes
   - Prominence of arms change

Classifiers:

First step: find a position angle

$$m_{x^2} = \sum_{i,j} \frac{I_{ij} x^2}{r^2}, \quad m_{y^2} = \sum_{i,j} \frac{I_{ij} y^2}{r^2}, \quad m_{xy} = \sum_{i,j} \frac{I_{ij} xy}{r^2},$$

$$\tan(2\phi) = \frac{2m_{xy}}{m_{x^2} - m_{y^2}} \qquad (1)$$

Even better: use the autocorrelation image

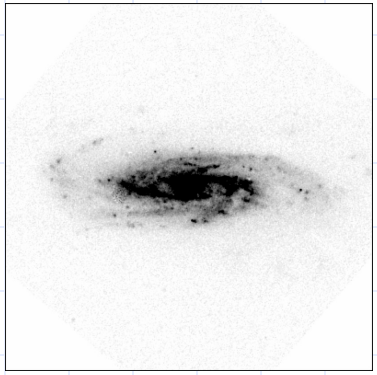
$$AC_{k,l} = \frac{\sum_{i,j}(I_{i,j} - \bar{I})(I_{i+k,j+l} - \bar{I})}{N_{k,l}} \qquad (2)$$

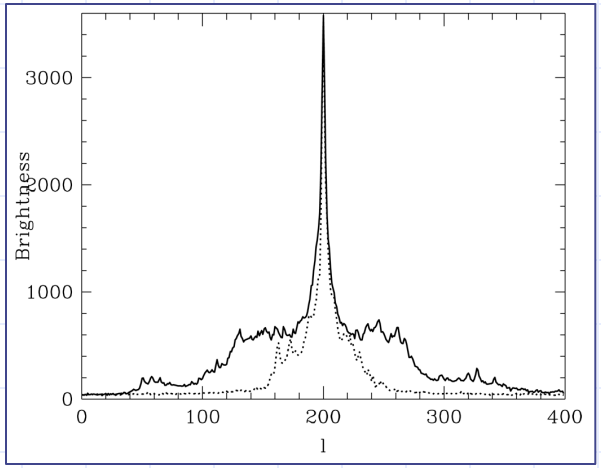
Second step: find the inclination angle

(a) from image moments:

$$I = \frac{\cos(2\phi)(m_{x^2} + m_{y^2}) + (m_{x^2} - m_{y^2})}{\cos(2\phi)(m_{x^2} + m_{y^2}) - (m_{x^2} - m_{y^2})} \qquad (3)$$

(b) from silhouettes:





Third step: disk-bulge decomposition

$$B_b(r) = B_e \exp(-7.67[(\frac{r}{r_e})^{1/4} - 1]) \quad , \qquad (4)$$

$$B_d(r) = B_0 \exp(-\frac{r}{r_0}) \qquad (5)$$

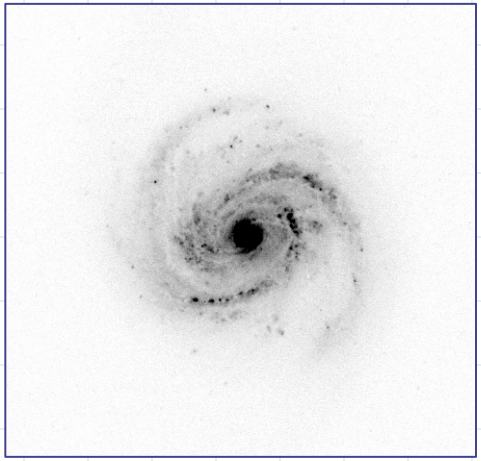
calculate the disk/bulge ratio:

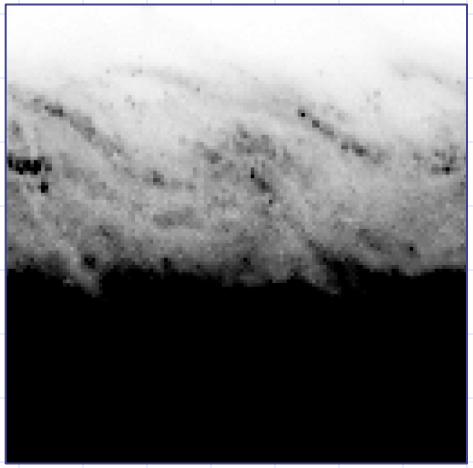
$$DB \equiv 0.277 \frac{B_0 r_0^2}{B_e r_e^2} \qquad (6)$$

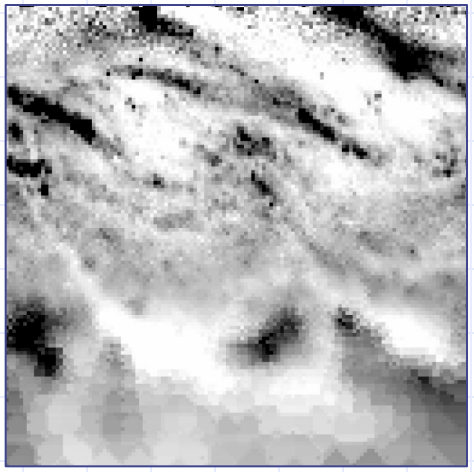
and the concentration index:

$$c \equiv 5 \log(\frac{r_{80}}{r_{20}}) \qquad (7)$$

Fourth step: Theta – log(r) pictures

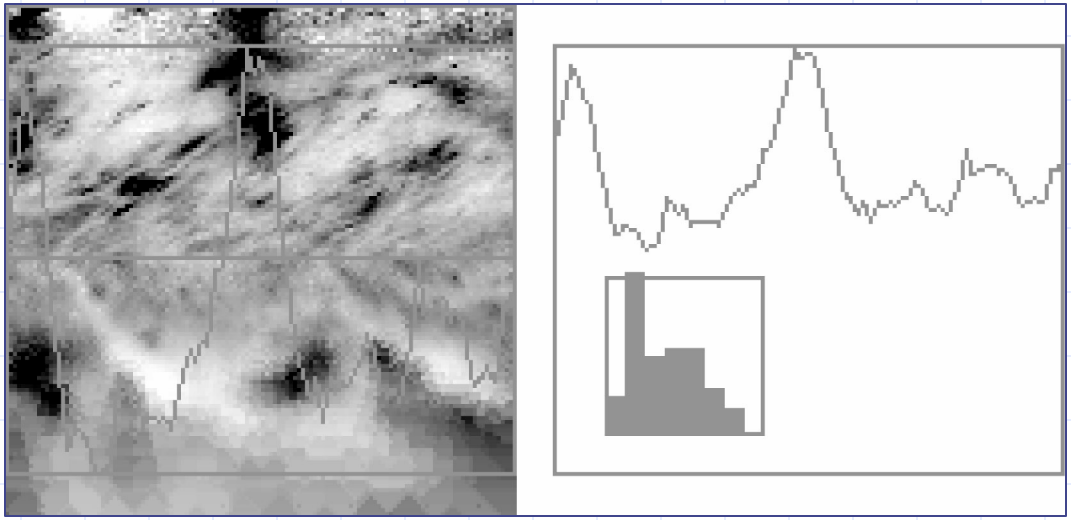






Use A.C. to get opening angles, and skew the Theta – log(r) image:

Collapse the image vertically and compute FFT to “count” arms:



Fifth step: fine scale structure of the disk

- Calculate the "interquartile range"
  (third quartile – first quartile divided by the median)
- Calculate the relative power of mode 0
  compared to the total power in FFT

Python framework

File Edit View Insert Cell Kernel Widgets Help

Not Trusted | Python 3 (ipykernel)

Basic morphological measures of nearby spiral galaxies

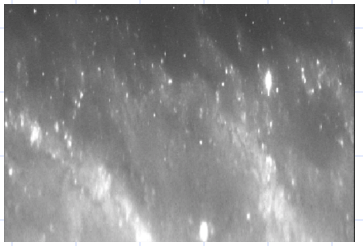
In [3]:
```
import numpy as np

# Set up matplotlib and use a nicer set of plot parameters
%config InlineBackend.rc = {}
import matplotlib
#matplotlib.rc_file("../../templates/matplotlibrc")
import matplotlib.pyplot as plt
import numpy as np
%matplotlib inline

from astropy.io import fits
import glob
```

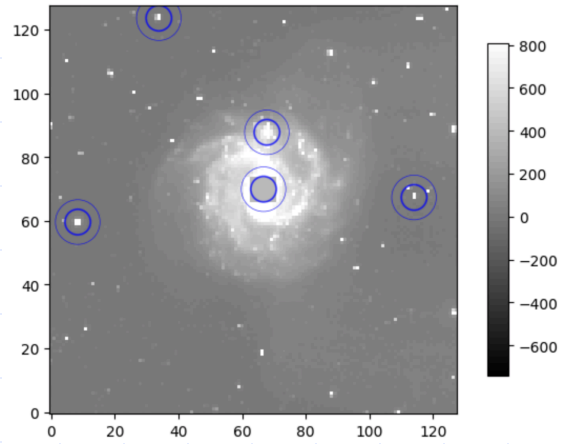
In [5]:
```
from photutils import DAOStarFinder, aperture_photometry
from photutils import centroid_com, centroid_1dg, centroid_2dg
from photutils import make_source_mask, Background2D, MedianBackground
from photutils import CircularAperture, CircularAnnulus
from astropy.table import hstack, vstack, Column
from astropy.stats import SigmaClip, biweight_location, mad_std, sigma_clipped_stats
```

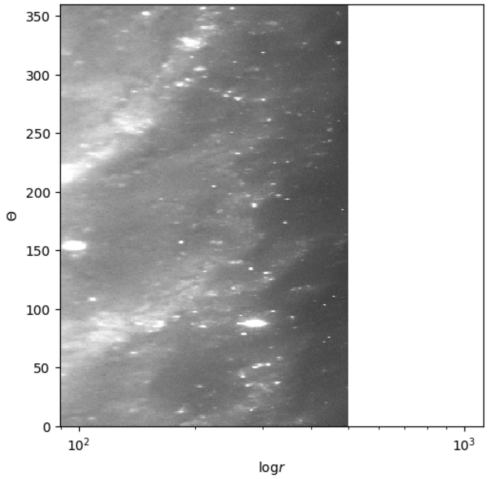
```
/tmp/ipykernel_22773/4032315326.py:2: DeprecationWarning: `photutils.centroid_com` is a deprecated alias for `photutils.centroids
```

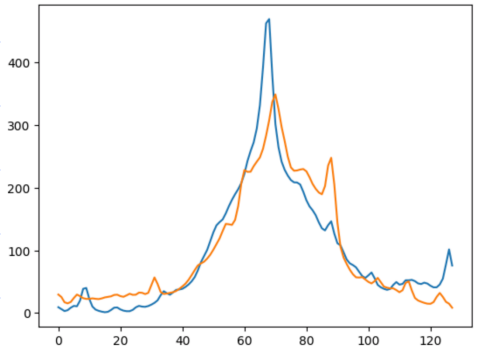
The output

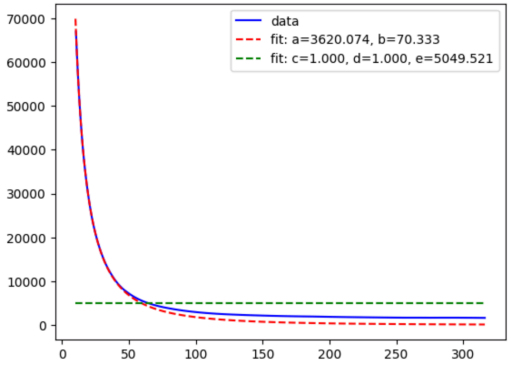
NGC3184







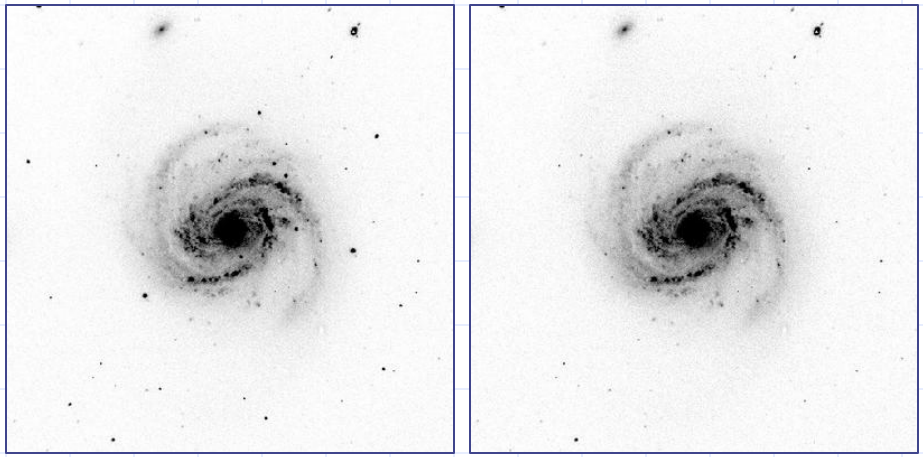





```
sn_per_pixel = 21.947061378516224
sky_mean = 6.292707567541064
sky_median = 5.597906636668327
sky_sigma = 2.813204161954199
xc_centroid = 67.69471437587902
yc_centroid = 70.56928422007844
rmax_circ = 60.2694446279419
rhalf_circ = 17.278218749893796
r20 = 8.838623729708125
r80 = 27.180794812272488
Gini = 0.4849594596607915
M20 = -1.3125513545584484
C = 2.4393875310195217
A = 0.34926627583119224
S = 0.07071020089938876
sersic_amplitude = 408.0854726155216
sersic_rhalf = 17.181947270986665
sersic_n = 0.7443466485119199
sersic_xc = 67.55323827014529
sersic_yc = 70.05001696284613
flag = 1
flag_sersic = 0
slice box = (slice(0, 12, None), slice(0, 12, None))
```

Tested on our existing catalog:

- 113 galaxies, CCD images taken at the Lowell Obs. and at Palomar
- Foreground-star removal:
  - Fit an empirical 2D PSF
  - Fit and remove stars
  - Patch residuals



Future tasks

Science:

- Optimization for large datasets and specific observations, Vera C. Rubin
- Developing new (better, parametric) statistical measures
- De-Mosaicking
- Galaxy dynamics and evolution constraints

Software:

- Automated pipeline - Rubin Contribution
- parallelization OpenMP, GPU, ML
- GitHub, Extensive set of example problems