

Galaxies: Structure, formation and evolution

Lecture 5

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Fainter galaxy components

such as shells and halos are too faint to fit but may be seen in the fit residuals.

Fainter you go the more you see.....



Duc et al 2011

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- accuracy of parameter estimation is strongly dependent on the accuracy of PSF and sky estimation. A small error in one of these can lead to a large error in galaxy parameter estimates. (lazy person's solution - use HST data, **Why?**)
- Nevertheless, quantitative morphology is widely (but not always wisely!) used today in many studies of galaxy evolution.

Quality control for bulge disk decomposition

- the reduced χ^2 is a quantitative goodness of fit indicator.
- in addition, the fit diagnostic plots were used to evaluate the quality of the fit
 - 1 are the residuals small and random?
 - 2 is the residual histogram approximately gaussian?
 - 3 does the radial profile pass through the azimuthally averaged data points?
 - 4 has the masking been done correctly?

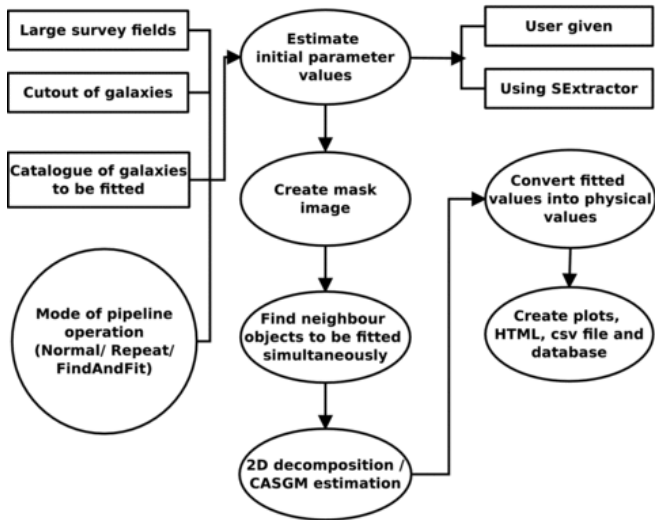
Some Bulge disk decomposition codes

- **fitgal** Wadadekar, Robbason & Kembhavi (1999). One of the earliest 2D codes. Uses Davidon-Powell-Fletcher variable metric algorithm from Minuit. Very fast. Not maintained anymore
- **galfit** Peng et al. 2002. The most widely used code. Uses the simple Levenberg-Marquardt algorithm. Very fast.
- **gim2d** Simard et al. 2002 uses the Metropolis algorithm similar to simulated annealing. Very slow but can handle low S/N images well.
- **BUDDA** de Souza et al. 2004

GALFIT can fit multiple galaxies simultaneously

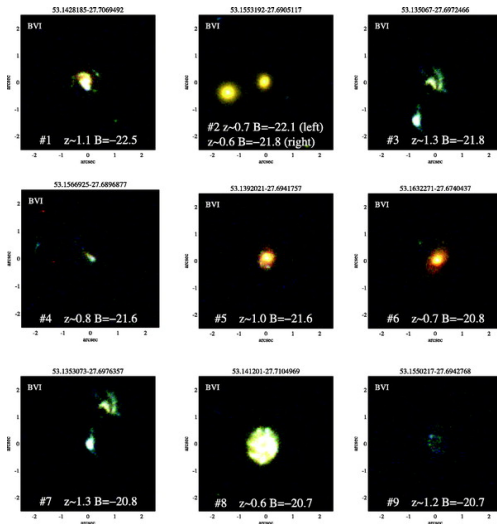


PyMorph pipeline



Vikram, Wadadekar et al. (2010)

When 2D decomposition does not work - use CAS or GM



Concentration index (C)

Concentration is defined as the ratio of the radius of the galaxy which contains 80% of the total light (r_{80}) to the radius of the galaxy which contains 20% of the total light (r_{20}). i.e.,

$$C = 5 \log \left(\frac{r_{80}}{r_{20}} \right) \quad (1)$$

How to measure or consistently define the “total light” of a galaxy?

Petrosian radius

The Petrosian radius r_p is the radius of the galaxy at which the Petrosian parameter η takes a value of 0.2. The Petrosian parameter is defined as follows:

$$\eta = \frac{\langle I_r \rangle}{\langle I \rangle_r} \quad (2)$$

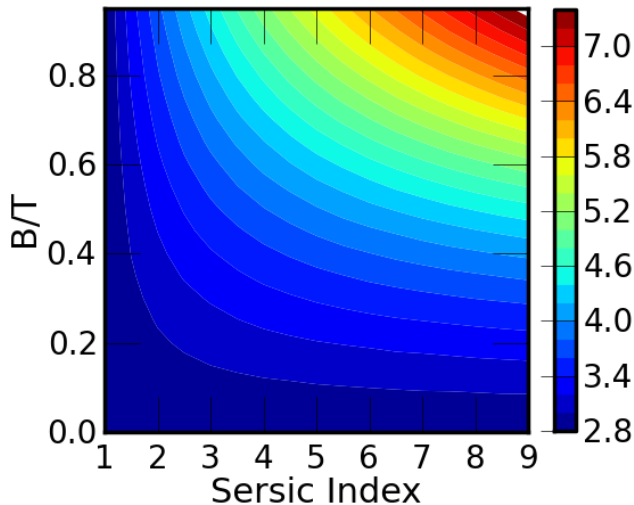
where $\langle I_r \rangle$ is the average light at the radius r and $\langle I \rangle_r$ is the average light inside r .

The total light of the galaxy is defined to be the light within 1.5 times of the Petrosian radius r_p

What is the connection between concentration index and morphology?

The theoretical value of concentration of an elliptical galaxy which follows $R^{1/4}$ law is 5.3 and that of a pure disk galaxy is 2.8. Therefore, the concentration is directly related to the B/T of the galaxy. Also it can be shown that the concentration parameter is related to the Sérsic index as the ellipticals have larger value of the index than disk galaxies. These correlations make the concentration a useful **non-parametric** quantity to classify galaxies. The three way analytical relation between these quantities, i.e. B/T , Sérsic index and concentration, can be derived.

Relation between $C, B/T$ and n



We rotate the galaxy through 180 degrees using bilinear interpolation about its centre which is taken to be the centroid (first image moment) of the galaxy pixels. In the next step, we subtract the rotated image from the original image of the galaxy. From the residual image we estimate the total residual flux inside the extraction radius. This is then normalised by the total flux of the galaxy. This step can be represented as follows:

$$A_O = \frac{\sum |I_0 - I_R|}{\sum I_0} \quad (3)$$

where I_0 and I_R are original image and the rotated image respectively and the summation is over all pixels, inside the radius R_T .

Question

How is asymmetry connected with morphology?

Clumpiness

To find S we convolve the galaxy image with a boxcar function of width $0.25r_p$ where r_p is the Petrosian radius of the galaxy. This smoothed image is then subtracted from the original image and the residual is summed within the extraction radius. The output of this process is the sum of the clumpiness of the object and background. The whole process can be summarised in the following equation:

$$S = 10 \left[\frac{\sum I_0 - I_S}{\sum I_0} \right] \quad (4)$$

where I_0 is the original image, I_S is the smoothed image and the summation is over all the positive pixels of residual image with the annular region of width $0.2R_T \leq r \leq R_T$.

Question

How is clumpiness related to morphology?

Gini coefficient

To get G we first find the pixels in the image which belong to the galaxy, i.e. obtain the **segmentation map** of the galaxy. For this, we convolve the galaxy image with a boxcar filter of size $r_p/5$. This process will increase the signal to noise ratio in the outer parts of the galaxy. Then we measure the intensity I_p at r_p . We assign all the pixels in image with $I_p \leq I \leq 10\sigma$ to the galaxy where σ is the standard deviation of the sky. The upper limit ensures that no cosmic rays or spurious pixels are included in the segmentation map. Then the pixels belonging to the segmentation map are sorted according to their photon count I_i and G is calculated using the equation:

$$G = \frac{1}{\bar{I}_i n(n-1)} \sum_{i=1}^n (2i - n - 1) |I_i| \quad (5)$$

where I_i is the photon count in the pixel i which belongs to the segmentation map, \bar{I}_i is the mean of all the pixel values I_i and n is the total number of pixels (Lotz et al 2004). $G=0$, implies complete equality.

Question

How will Gini be affected if we get the segmentation map wrong? Will the Gini coefficient be higher in ellipticals compared to spirals?

Second order moment of the brightest pixels (M_{20})

This quantity measures of how the brightest pixels are distributed over the galaxy segmentation map. To compute M_{20} we use the segmentation map generated to estimate the Gini coefficient. We start by computing the flux weighted second order moment of the galaxy M_T as

$$M_T = \sum M_i = \sum I_i \left[(x_i - x_c)^2 + (y_i - y_c)^2 \right] \quad (6)$$

where I_i , x_i , y_i are the flux value and x and y coordinates of the i^{th} pixel in the segmentation map and x_c and y_c are the initial centre of the galaxy. We then minimize M_T with respect to the centre of the galaxy as the initial value of the centre is the centroid of the galaxy.

We sort the pixels according to their flux value and find the moment of the 20% brightest pixels of the galaxy using the equation

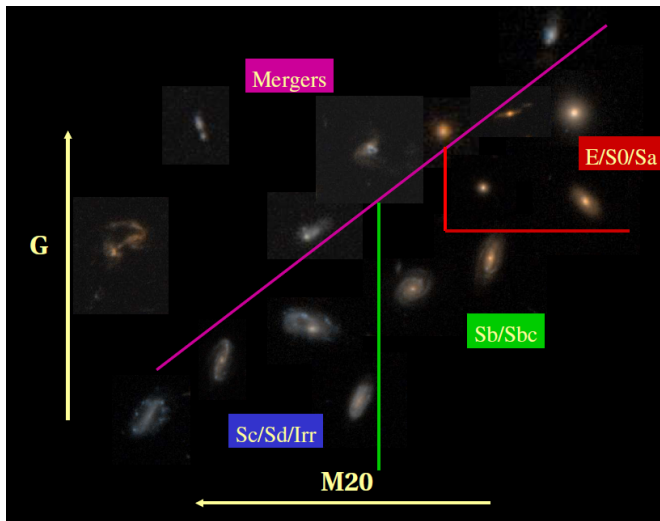
$$M20 = \log \left(\frac{\sum M_i}{M_T} \right) \quad (7)$$

where the summation continues until it satisfies $\sum I_i \leq 0.2 I_T$ where i is the pixel in the sorted array of the segmentation map and I_T is the total light of galaxy.

Question

If you observe the same spiral galaxy in a blue and red filter where will the M20 be higher and why? Is M20 similar to the concentration parameter?

Gini+M20 and galaxy morphology



Large scale structure of galaxies

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So far, we have looked at galaxies and their components from a structural point of view. The physical scale is a few 10s of kiloparsecs. Now we look at the large scale structure of baryons in the universe on Mpc scales. Just as stars are the individual building blocks of galaxies, galaxies are building blocks of the *cosmic web* of large scale structure. Remember, however, that galaxies are *biased* tracers of the underlying DM distribution i.e. M/L ratio is not constant!