# Velocity dispersion in elliptical galaxies

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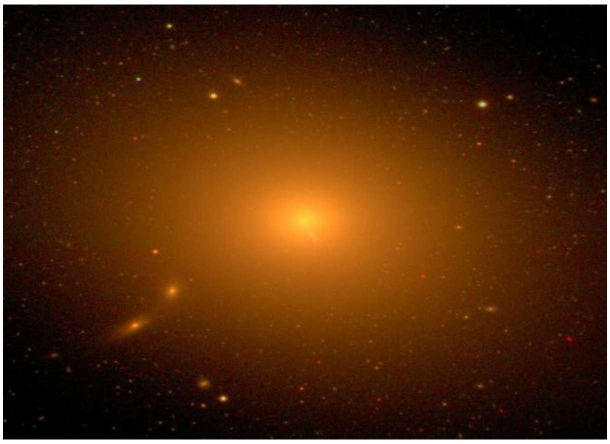
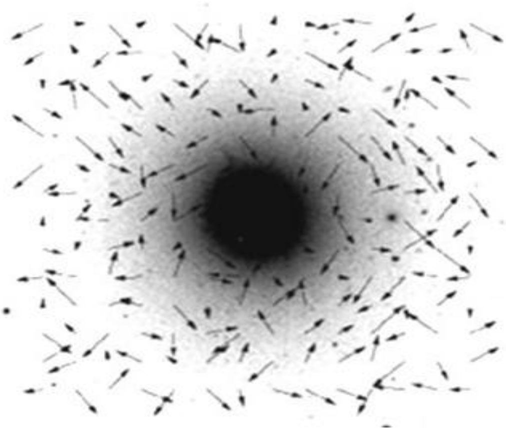
ABSTRACT

*The aim of our experience is to calculate the velocity dispersion of the stars in elliptical galaxies through the cross-correlation technique, undertaken by Tonry and Davis (1979). Relating this parameter to the effective radius, obtained by morphological analysis, it is also possible to calculate the mass of the galaxy, and verify how mass and velocity dispersion are related.*

## I. INTRODUCTION



An elliptical galaxy has an approximately elliptical shape and is composed mostly of old stellar populations (classes GKM). Its spectrum is the sum of the spectra of the stars which is made of. The stars of elliptical galaxies have a chaotic motion and the radial components of their velocity vectors generate shifts in their spectra. The result is the sum of similar but differently shifted spectra, which produce a broadening of the absorption lines. This information allows us to apply the cross-correlation technique, which consists of making a comparison between a galaxy spectrum and an old star spectrum, used as a template to determine the velocity dispersion which gives an indication about the chaotic orbits of stars around the centre of mass of the galaxy.
Velocity dispersion grows with mass: the more massive the galaxy is, the more gravity makes the motion chaotic.



## II. OBSERVATIONAL DATA

The data were taken from the database of the Sloan Digital Sky Survey (www.sdss.org) because bad weather conditions did not allow us to observe the sky directly. This archive contains data of about 230 million astronomical objects like stars, galaxies and quasar, contained in a quarter of the sky and taken by a 2.5m telescope situated in the Apache Point Observatory, New Mexico.
Searching among the red galaxies with redshift between 0 and 0.1, to guarantee a sufficient spatial resolution, we selected 13 elliptical galaxies. The selection was made observing both images and spectra (which contain data of the central zone of the galaxy, about 3"), in which the Hα line had to be in absorption. This happens because the photosphere of the stars is colder than the inner layers, so it absorbs part of the radiation which goes through it. Then, the radiation is re-emitted, but in a different direction, causing lack of light at some wavelength, so the stellar spectrum has a Planck curve shape with many absorptions.

Elliptical galaxies are dominated by old stars light, therefore their spectra are similar to a mix of a G and K star spectrum. In spiral galaxies, where often hot stars are present, there are large zones of ionized gas which produce spectra with emission lines.

We downloaded spectra and redshift values of the following galaxies.

| nr | Galaxy name | Redshift |
|---|---|---|
| 1 | SDSS J135039.09+350217.9 | 0.021 |
| 2 | SDSS J133440.34+325704.0 | 0.024 |
| 3 | SDSS J161845.79+392004.0 | 0.032 |
| 4 | SDSS J153215.71+092755.9 | 0.033 |
| 5 | SDSS J162754.90+403621.9 | 0.033 |
| 6 | SDSS J105807.60+091634.0 | 0.034 |
| 7 | SDSS J080550.30+372736.1 | 0.034 |
| 8 | SDSS J030352.91+002454.9 | 0.043 |
| 9 | SDSS J124622.67+115235.7 | 0.044 |
| 10 | SDSS J141532.92+501051.7 | 0.044 |
| 11 | SDSS J084051.14+315853.4 | 0.047 |
| 12 | SDSS J075638.85+440741.0 | 0.047 |
| 13 | SDSS J100910.07+541331.9 | 0.048 |

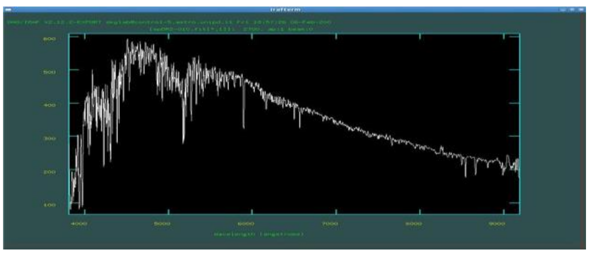


Fig. 3: Spectrum of the template star.

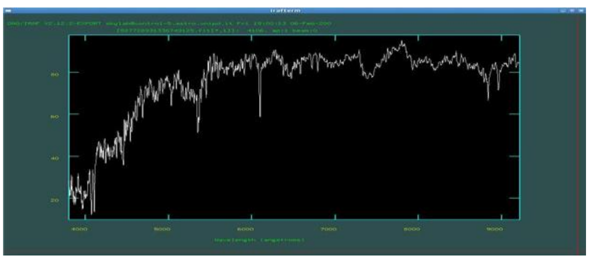
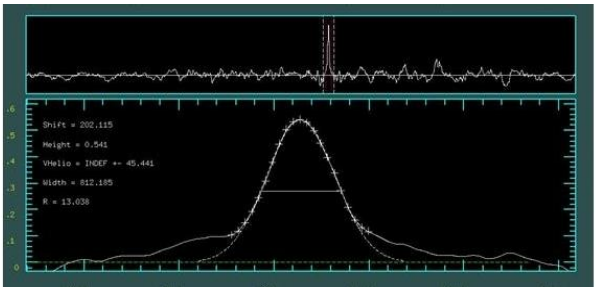


Fig. 4: Example of spectrum of an elliptical galaxy.

## III. WORK DESCRIPTION

Once we selected the galaxies spectra to study, we compared them with the template star, subtracting from both spectra their continua and removing their different shapes.

The comparison was made with the program FXCOR of IRAF package, which decomposes every signal in a sum of sinusoidal functions through the Fourier transformation(1). The product of the transformed signals generates the correlation function, which is similar to a Gaussian function. The stronger the




correlation is, the higher the peak of the curve is, to a maximum of 1 for the perfect correlation, i.e. autocorrelation.

More in detail, the peak height is index of the superposing grade of the two spectra: it depends on the presence of the same absorption or emission lines.

The program also measures the width of the peak at the middle height (FWHM), which is useful to calculate the velocity dispersion.

First of all we need to calculate the intrinsic FWHMi:

$$\mathrm{FWHMi} = \sqrt{\mathrm{FWHM}^2 - \mathrm{FWHMa}^2}$$

where FWHM is obtained correlating galaxy and template, while FWHMa is the autocorrelation of the template spectrum.

Once the intrinsic FWHMi is calculated, the velocity dispersion can be found with the following formula:

$$\sigma = \frac{\mathrm{FWHMi}}{2.35}$$

Once every galaxy dispersion is measured, we calculated the average and standard deviation, which gives an indication about how much the average is representative of the measurements:

$$\overline{\sigma} = \frac{\sum \sigma_i}{N} \qquad \sigma = \sqrt{\frac{\sum(\sigma_i - \overline{\sigma})^2}{(N-1)}}$$

To calculate the mass we used the formula(2):

$$M = \frac{r_e \cdot \sigma^2}{0.33 \cdot G}$$

Where $r_e$ is the effective radius, i.e. the radius within which half of the galaxy light is contained and it gives an estimate of the luminosity distribution of the stars (the shorter the radius is, the more stars are concentrated in the centre of the galaxy); its value had been calculated in arcsec by Guerra, Mannino, Paccagnella (see their report *Morphological study of elliptical galaxies*) and then converted into km by means of the distance D:

$$D = \frac{c \cdot z}{H_0}$$

where z is the redshift and $H_0$ = 72 km $s^{-1}$ $Mpc^{-1}$ is the Hubble constant, and the scale in Mpc/arcsec:

$$scale = \frac{D}{206265}$$

Every value obtained was put in the following table:

| nr | D(Mpc) | D(Km) | Ref(") | Scale | Ref(Km) |
|---|---|---|---|---|---|
| 1 | 87.5 | 2.7E+21 | 11.7 | 1.31E+16 | 1.53E+17 |
| 2 | 100. | 3.09E+21 | 10.5 | 1.5E+16 | 1.57E+17 |
| 3 | 133.33 | 4.12E+21 | 9.0 | 2.0E+16 | 1.8E+17 |
| 4 | 137.5 | 4.25E+21 | 7.7 | 2.06E+16 | 1.59E+17 |
| 5 | 137.6 | 4.25E+21 | 2.0 | 2.06E+16 | 4.12E+17 |
| 6 | 141.7 | 4.38E+21 | 12.5 | 2.12E+16 | 2.65E+17 |
| 7 | 141.7 | 4.38E+21 | 6.6 | 2.12E+16 | 1.4E+17 |
| 8 | 179.2 | 5.54E+21 | 15.0 | 2.68E+16 | 4.03E+17 |
| 9 | 183.3 | 5.67E+21 | 11.4 | 2.75E+16 | 3.13E+17 |
| 10 | 183.3 | 5.67E+21 | 7.0 | 2.75E+16 | 1.92E+17 |
| 11 | 195.8 | 6.05E+21 | 8.0 | 2.93E+16 | 2.35E+17 |
| 12 | 195.8 | 6.05E+21 | 20.5 | 2.93E+16 | 6.01E+17 |
| 13 | 200. | 6.18E+21 | 11.3 | 3.0E+16 | 3.39E+17 |

The purple colour indicates the non elliptical galaxies, chosen in order to have a comparison term with the elliptical ones. In particular, the spiral galaxy has a very low correlation index compared to the others, since its spectrum is very different from that of the template star, being formed mainly by young stars (O-B spectral class).
The red colour indicates the galaxies with uncertain morphology, which have not been completely studied.
For the other excluded galaxies the correlation gave indexes similar to those of the ellipticals, but this does not mean that they actually are elliptical. In fact our colleagues did not classify them as elliptical.
Thus the stellar velocity dispersion, the effective radius and the mass were calculated only for the elliptical galaxies.

## IV. RESULTS

We have selected 13 elliptical galaxies to measure the stellar velocity dispersion and calculate their mass.
We compared the nuclear spectra of these galaxies with template star spectra by means of the cross-correlation method to determine the stellar velocity dispersion.
The average σ value is 250 ± 50 km/s. The effective radius of the same galaxies were measured by our colleagues who studied their morphology.
Finally we applied the Virial theorem to estimate the total mass.
The average M value (in solar masses) is $4 \pm 3 \cdot 10^{11}$.
The values are listed in the following table.

| nr | M (Mo) | R (") | σ (Km/s) |
|---|---|---|---|
| 1 | 4.95E+10 | 2.00 | 229.96 |
| 2 | 1.01E+11 | 11.70 | 169.88 |
| 3 | 1.22E+11 | 10.50 | 184.96 |
| 4 | 1.48E+11 | 6.60 | 215.48 |
| 5 | 2.24E+11 | 9.00 | 234.43 |
| 6 | 2.28E+11 | 11.30 | 172.21 |
| 7 | 2.77E+11 | 7.70 | 277.47 |
| 8 | 3.05E+11 | 7.00 | 264.41 |
| 9 | 4.19E+11 | 8.00 | 280.18 |
| 10 | 6.35E+11 | 12.50 | 324.57 |
| 11 | 6.73E+11 | 11.40 | 307.71 |
| 12 | 8.47E+11 | 15.00 | 304.30 |
| 13 | 1.00E+12 | 20.50 | 270.59 |

## V. BIBLIOGRAPHY:

All data were found in:
–Sloan Sky Digital Survey archives;
–Theoric issues given during the course;
–The article "A Survey of Galaxy Redshifts. Data Reduction Techniques" by Tonry and Davis, The Astronomical Journal, vol. 84, num. 10, october 1979.

## VI. NOTES

*1.* $$F(a) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{\infty} f(u) e^{iau} du$$

*2.* The formula used to calculate the mass comes from the Virial theorem, following the relation:

$$2E_k + U = 0$$

$$Mv^2 - \frac{GM^2}{r} = 0$$

$$M = v^2 \frac{r}{G}$$

$$v = const \cdot \sigma$$

$$M = \sigma^2 \frac{r}{G} \cdot \frac{1}{0.33}$$