



# Photometric and spectroscopic analysis of Abell 779

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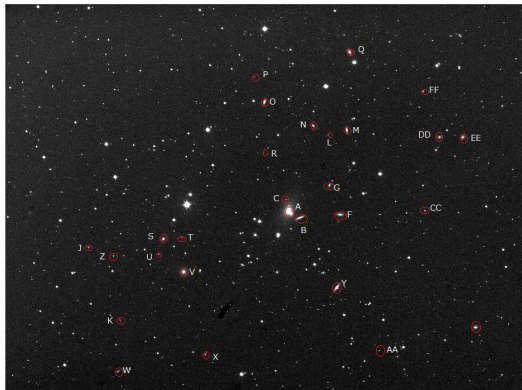
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**Abstract** Our goal was to determine the total mass of the cluster Abell 779 through the photometric and spectroscopic analysis of some of its galaxies. We used a dynamic approach to perform the analysis. The photometric analysis, realized on R-band images taken at the Asiago Schmidt telescope, allowed us to determine the luminosity of each galaxy. On the other hand, the analysis of the spectra taken at the 1.22m Galileo telescope allowed us to determine the redshift of each object. We could, therefore, select the galaxies belonging to the cluster, and by using the measurement of the radial velocities, we calculated the average velocity dispersion. This parameters allowed us to calculate, together with the harmonic radius through the photometric measurements, the total mass of the cluster.

## 1. Introduction

Galaxy clusters are among the most massive and largest known objects in the universe (they are second only to super-clusters) with a diameter of about 8-9 Mpc. They contain a minimum of 50 galaxies and an enormous quantity of intergalactic gas, which can have a mass twice the total mass of the galaxies, and very high temperatures, around ten millions Kelvin, which make the gas emit X-rays and therefore become observable. In addition, gas and galaxies interact gravitationally.



**Figure 1.** r-band image of Abell 779. The red circles indicate the galaxies with available spectrum.

## 2. Observational Data

For the photometric analysis, we used an *R*-band image taken with the Asiago Schmidt telescope (OAPd/INAF) which uses the SBIG STL-11000M CCD. The *R* filter was used to select a region of the electromagnetic spectrum centred on the average wavelength of 6165Å. For the spectroscopic analysis, we used the spectra taken with the 1.2-m Galileo telescope (Padova University). The object we considered was the galaxy cluster Abell 779; we also examined the spectrum of twenty of its galaxies. The coordinates are:

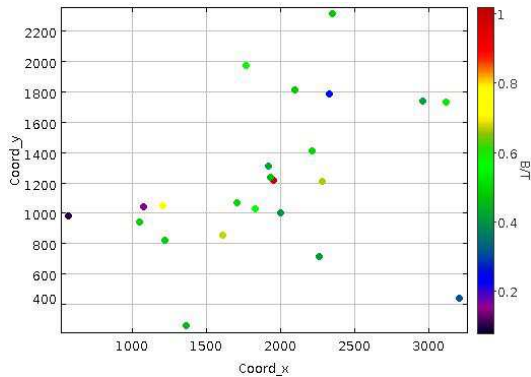
| Object          | Abell 779    |
|-----------------|--------------|
| Right ascension | 09h 19m 52s  |
| Declination     | +33° 45m 22s |
| Constellation   | Lynx         |

## 3. Work Description

We analyzed the Abell cluster 779 using a dynamic method, which consisted in taking into account the various typologies of energy found in the cluster. This procedure allowed us to manage the data without referring to one single galaxy at a time. The relation between the different forms of energy is expressed by the application of the Virial Theorem, which implies the use of the stellar velocity dispersion and harmonic radius of the cluster. The harmonic radius is an estimate of the radius of the cluster. The photometric analysis had the purpose of determining the morphological parameters of the galax-

ies, and the creation of a model representing the surface brightness distribution of each galaxy. The program we used is GIM2D, which works in IRAF. First, we had to obtain the Point Spread Function (PSF), which is a model describing the image of a point source. We used the IRAF package DAOPHOT to perform the photometry of 20 stars and calculate the average PSF. Finally, we created an image of the PSF. The program SExtractor allowed us to recognize and deblend the sources in the image; the result was a mask in which all the sources were detected and represented by different colors to distinguish them. By using the mask and the output catalogue produced by SExtractor, we could identify the galaxies belonging to the cluster to be studied, extracting all the needed data.

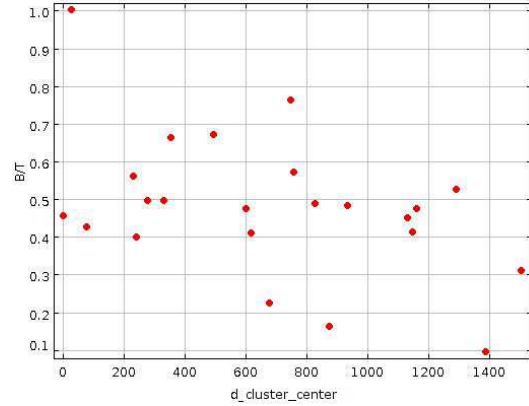
The data were processed using GIM2D, which provided us with morphological parameters and 4 images for each object: a thumbnail of the object from the original image, its mask, its mathematical model, and the residual image. Then, we analyzed some outputs, such as: the total luminosity of the galaxy,  $L_{tot}$ , the ratio between the bulge luminosity and the total luminosity of the galaxy, B/T, and the Sérsic index, which is one of the parameters of the Sérsic function that control the surface-brightness radial profile of the galaxy. The two last outputs are useful to identify the morphology of the galaxies. In fact, the B/T ratio refers to the prominence of the bulge in relation to the rest of the galaxy: if this parameter is equal to 1, the galaxy is elliptical. When the Sérsic index, that is approximately within the range 0.5-10, is equal to 4, the de Vaucouleurs law is reproduced: it describes the surface-brightness distribution of the elliptical galaxies. When the index is equal to 1 the exponential profile is reproduced: it describes the surface-brightness distribution of the disk of the spiral and lenticular galaxies. In Fig. 2 we show how the B/T values of the examined galaxies are distributed in the field of view.



**Figure 2.** Distribution of the B/T values of the sample galaxies in the field of view.

Statistically, the elliptical galaxies in clusters are distributed more towards the centre; even in this case,

as shown in Fig.2, it is noticeable that the majority of the elliptical galaxies and the ones with the B/T value close to 1 is concentrated in the centre of the cluster.



**Figure 3.** B/T values of the sample galaxies versus their distances from the centre of the cluster.

| Name | Ltot   | redshift(z) | B/T |
|------|--------|-------------|-----|
| A    | 797951 | 0.017       | 1.0 |
| BB   | 292332 | 0.024       | 0.3 |
| C    | 57296  | 0.024       | 0.4 |
| DD   | 192316 | 0.024       | 0.4 |
| E    | 302931 | 0.024       | 0.5 |
| EE   | 276973 | 0.022       | 0.5 |
| F    | 468843 | 0.027       | 0.7 |
| G    | 171676 | 0.019       | 0.5 |
| H    | 15512  | 0.019       | 0.6 |
| I    | 14380  | 0.021       | 0.4 |
| M    | 272212 | 0.025       | 0.2 |
| N    | 204227 | 0.022       | 0.5 |
| O    | 404271 | 0.025       | 0.6 |
| Q    | 367106 | 0.024       | 0.5 |
| S    | 41492  | 0.023       | 0.5 |
| T    | 30929  | 0.023       | 0.8 |
| U    | 196360 | 0.022       | 0.2 |
| V    | 611605 | 0.028       | 0.5 |
| X    | 70987  | 0.024       | 0.5 |
| Y    | 715272 | 0.021       | 0.4 |

**Table 1.** Total luminosities, redshifts, and ratios between the luminosity of the bulge and the total luminosity of the sample galaxies.

Afterwards, we started determining the magnitudes.  $L_{tot}$  was converted in counts/s dividing it by the exposure time ( $t_{exp}$ ), and so it was possible to calculate the calibrated magnitude in the R band with the formula:

$$m_{cal} = m_o - kx - 2.5 \log(L_{tot}/t_{exp})$$

where  $m_o = 23.32$ ,  $k = 0.12$  is the extinction coefficient in magnitudes per airmass, and  $x$  is the airmass.

Moreover, the calibrated magnitudes of the bulge and disk were obtained through the formulas:

$$m_{cal}^{bulge} = m_0 - kx - 2.5 \log \left( \frac{L_{tot}}{t_{exp}} B/T \right)$$

$$m_{cal}^{disk} = m_0 - kx - 2.5 \log \left[ \frac{L_{tot}}{t_{exp}} (1 - B/T) \right]$$

Then, we analyzed the spectra of the galaxies, taken at the 1.2m Galileo telescope. We compared the profile of each spectrum with the one of a generic star to identify the absorption and emission lines of specific elements. At this point, we calculated the redshift,  $z$ , of each galaxy. We considered the  $H\alpha$ , CaK, G-band, Mg, and Na lines, and we applied the formula:

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c}$$

where  $\lambda$  is the observed wavelength and  $\lambda_0$  is the rest-frame one;  $c$  is the speed of light, and  $v$  is the radial velocity, which is positive if the object is moving away from the observer, and negative if it moves towards the observer. Only the objects with  $z$  included in a certain range, whose centre is the average  $z$  of the cluster, are part of the cluster itself. The redshift was useful to determine the distance,  $D$ , between the object and Earth, with the formula:

$$D = \frac{cz}{H_0}$$

where  $H_0$  is the Hubble constant, equal to  $72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ .

Once  $D$  was determined, we could obtain the absolute magnitude of each galaxy by using the equation:

$$M = m + 5 - 5 \log(D)$$

where  $D$  is in units of pc. Afterwards, to obtain the luminosity in units of solar luminosities, we applied the formula:

$$L = 10^{-0.4(M-M_\odot)} L_\odot.$$

With the luminosity of each galaxy we could proceed determining the harmonic radius through the formula:

$$R_h = \frac{\sum L_i^2}{2 \sum \frac{L_i L_j}{R_{ij}}} = 0.037 \text{ Mpc}$$

Finally, we used the Virial Theorem to calculate the mass of the cluster,  $\mathcal{M}$ , using the following formula:

$$\mathcal{M} = \frac{3\pi}{G} R_h \sigma^2$$

where  $\sigma$  is the velocity dispersion. The result was  $\mathcal{M} = 2.24 \times 10^{14} \text{ kg}$ , equivalent to approximately  $10^{14} \mathcal{M}_\odot$ .

Table 2 describes the data we collected during the experience. We included the principal properties of the analyzed galaxies.

| Name | Coord_x | Coord_y | Lum                  |
|------|---------|---------|----------------------|
| A    | 1950    | 1210    | $9.3 \times 10^{45}$ |
| BB   | 3207    | 434     | $4.5 \times 10^{45}$ |
| C    | 1915    | 1305    | $1.1 \times 10^{44}$ |
| DD   | 2961    | 1730    | $1.7 \times 10^{45}$ |
| E    | 1705    | 1064    | $4.4 \times 10^{45}$ |
| EE   | 3120    | 1729    | $2.7 \times 10^{45}$ |
| F    | 2283    | 1202    | $2.2 \times 10^{46}$ |
| G    | 2211    | 1402    | $4.9 \times 10^{44}$ |
| H    | 1830    | 1022    | $1.8 \times 10^{42}$ |
| I    | 1998    | 996     | $2.4 \times 10^{42}$ |
| M    | 2329    | 1778    | $4.4 \times 10^{45}$ |
| N    | 2100    | 1807    | $1.2 \times 10^{45}$ |
| O    | 1767    | 1970    | $1.1 \times 10^{46}$ |
| Q    | 2348    | 2310    | $7.0 \times 10^{45}$ |
| S    | 1046    | 933     | $3.6 \times 10^{43}$ |
| T    | 1205    | 1044    | $1.9 \times 10^{43}$ |
| U    | 1077    | 1037    | $1.5 \times 10^{45}$ |
| V    | 1216    | 813     | $4.9 \times 10^{46}$ |
| X    | 1364    | 250     | $1.6 \times 10^{44}$ |
| Y    | 2261    | 706     | $2.0 \times 10^{46}$ |

**Table 2.** Coordinates in pixel and luminosities ( $\text{erg s}^{-1}$ ) of the sample galaxies.

#### 4. Conclusions

We performed a photometric and spectroscopic analysis of the galaxy cluster Abell 779. Our sample consisted of 20 galaxies. We performed a two-dimensional photometric decomposition of each galaxy surface-brightness distribution using the GIM2D fitting algorithm. Then, we classified the morphology of the galaxies and derived their luminosities. The spectroscopic analysis allowed us to measure an average  $z = 0.023 \pm 0.003$ , proving that the whole sample belongs to the cluster. We derived the radial velocities of the galaxies and the velocity dispersion. At the end, we applied the Virial Theorem to calculate the mass of the cluster, which resulted to be  $\mathcal{M} = 10^{14} \mathcal{M}_\odot$ . The result, which was obtained through a dynamical method, accounts for both the luminous and dark matter components.

