

Photometry and spectroscopy of HCG 61

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Abstract. We studied the galaxy group HCG 61 through a photometric and spectroscopic analysis which allowed us to determine the morphological classification and recessional velocity of each galaxy, and the distance and mass of the group.

1. Introduction

Galaxy groups are the smallest aggregates of galaxies in the Universe and, with clusters, the largest known gravitationally bound systems. They are usually composed by less than fifty galaxies, in a diameter of a few million light-years and a mass value of approximately $10^{13} M_{\odot}$.

The objects identified with HCG (Hickson Compact Group) are an ensemble of a hundred groups, classified by Paul Hickson in 1982, and characterized by a relatively small number of galaxies, very close to one another (distances are comparable to galaxy sizes), bound by a gravitational field.

The object we analyzed is HCG 61, also known as The Box.

Object	HCG 61
RA	12h12m 29.3s
Dec	+29d 10m 40s
Constellation	Coma Berenices
Angular size	228 arcsec

Our work included a photometric and spectroscopic analysis of the four main galaxies of the group: NGC 4169, NGC 4173, NGC 4174, and NGC 4175. Photometry, through the study of the flux we receive from the objects, allows the determination of the morphological class (according to the Hubble's classification) and the values of the apparent magnitude of each galaxy. Spectroscopy instead provides plenty of physical parameters, e.g., redshift, distance, and mass, firstly of the single galaxies and then of the whole group.

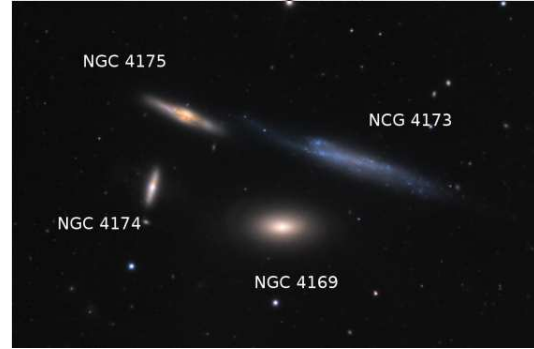


Fig. 1. Galaxy group HCG 61.

2. Observational Data

For our work, we used data taken both from the online archive of the Sloan Digital Sky Survey (SDSS) and the telescope of the Asiago Astrophysical Observatory.

The SDSS used a dedicated 2.5 m telescope at the Apache Point Observatory, New Mexico, equipped with two powerful special-purpose instruments. The CCD, constituted by 120 megapixels, has a field of view of 1.5 square degrees. From the online archive we downloaded the FITS images of the whole group and the spectra of the galaxies NGC 4173, NGC 4174, and NGC 4175 in FITS format.

The reflector telescope Galileo of the Astrophysical Observatory of Asiago mounts a primary mirror with a diameter of 1.2 m and it is used to provide spectra. The spectrum of the last galaxy, NGC 4169, was obtained with it.

3. Work description

We started the photometric analysis, in the r -band, displaying the FITS image of the group using the software DS9, and drawing an ellipse around the outskirts of each galaxy. After that, we created the isophotes with the IRAF task ellipse.

The isophotes are the lines that join the points of the galaxy with the same surface brightness.

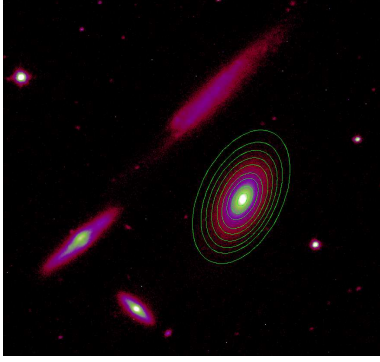


Fig. 2. Isophotes on NGC 4169 displayed with DS9.

We set up the task parameters (e.g., centre, ellipticity, and maximum semi-major axis) and we masked the stars interposed between us and the galaxy that could affect the isophotes.

With the isophotal parameters we were able to derive the surface-brightness radial profile of the galaxy. We displayed the profile in a cartesian plot, using the software TOPCAT.

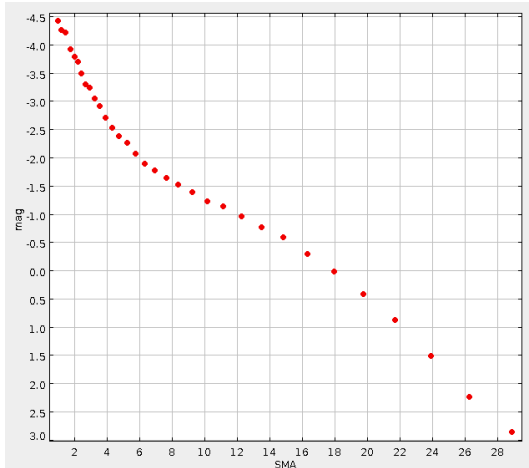


Fig. 3. Surface-brightness profile of NGC 4175 produced with TOPCAT.

The surface-brightness profile can be used to estimate the galaxy morphological classification, since from its analysis it is possible to classify the galaxy as an elliptical, spiral, or irregular one. To determine the

exact classification it is necessary to measure the ratio between the total luminosity of the bulge (the central spheroid) and the disk. Therefore, we fitted the surface-brightness profile with the de Vaucouleurs' empirical law and the exponential-disk function, to find out the parameters needed to calculate the luminosities of the two components: the effective radius, r_e , the effective surface brightness, I_e , the scale length, h , and the central surface brightness, I_0 . At this point we were able to calculate the total luminosity of the bulge and the disk using the following expressions:

$$L_{\text{bulge}} = 7.22 \cdot \pi \cdot I_e \cdot r_e^2 \quad (1)$$

$$L_{\text{disk}} = 2 \cdot \pi \cdot I_0 \cdot h^2 \quad (2)$$

The ratio between the two luminosities, which we converted into a difference in magnitudes through the Pogson's formula, allows to determine the morphological class of the galaxy using the T-type scale.

We repeated this procedure for each galaxy.

For the spectroscopic analysis we displayed the galaxy spectra using the task SPLIT of IRAF.

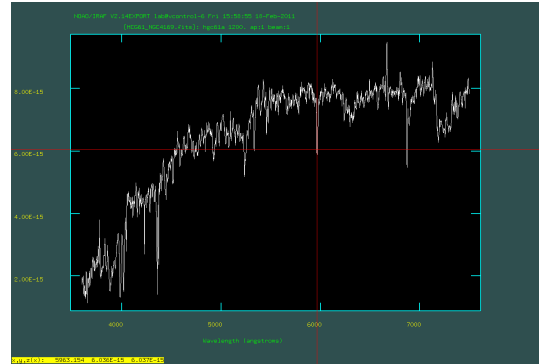


Fig. 4. Spectrum of NGC 4169 displayed with split.

To calculate the redshift, due to the expansion of the Universe, we estimated the difference between the wavelengths of the observed lines and the laboratory ones. The examined lines were:

Line	Rest-frame wavelength
CaK	3934 Å
G-band	4304 Å
H β	4861 Å
Mg	5175 Å
Na	5891 Å
H α	6562 Å
CaII	8498 Å- 8542 Å- 8662 Å

We calculated the redshift, $z = \Delta\lambda/\lambda_0$, for each line and then we considered the average value. Measuring the Doppler shift, we found the recessional velocity, $v = zc$, and, applying Hubble's law, the distance, $d = v/H_0$.

To determine the mass it was necessary to calculate the standard deviation of the velocity, the luminosity of each galaxy, and the harmonic radius.

We calculated the standard deviation through the formula:

$$\sigma = \sqrt{\frac{\sum_i (v_i - \bar{v})^2}{n - 1}} \quad (3)$$

For the luminosity values we used the ones obtained with the photometric analysis, which we changed into calibrated magnitudes:

$$\text{mag}_{\text{cal}} = m_0 - kX - 2.5 \log(I_{\text{bulge}} + I_{\text{disco}}) \quad (4)$$

where m_0 is a constant depending on the filter, k is the atmospheric extinction coefficient, and X is the airmass. Through the distance it was possible to derive the absolute magnitude:

$$\text{Mag} = \text{mag}_{\text{cal}} + 5 - 5 \log(d) \quad (5)$$

We obtained the luminosities in unit of $L_{\odot}$:

$$L = L_{\odot} \cdot 10^{-0.4(\text{Mag} - \text{Mag}_{\odot})} \quad (6)$$

The harmonic radius was calculated from the luminosities of the galaxies and their reciprocal distances, by applying the formula:

$$R_H = \frac{2 \sum_i L_i^2}{\sum_{i \neq j} \frac{L_i L_j}{R_{ij}}} \quad (7)$$

Finally, applying the Virial theorem, we determined the mass of the group:

$$M = \frac{3\pi}{G} \cdot \sigma^2 \cdot R_H \quad (8)$$

4. Results

We report in the following table the results of the morphological classification:

Galaxy	$L_{\text{bulge}}/L_{\text{disk}}$	Δmag	Class
NGC 4169	0.4864	0.7824	S0/a
NGC 4173	0.0266	3.9361	Sb-c
NGC 4174	0.3697	1.0802	Sa
NGC 4175	0.2127	1.6804	Sa

The classes we established for NGC 4169, NGC 4174, and NGC 4175 are in agreement with those found in literature. NGC 4173 was particularly hard to classify because of its irregular surface-brightness profile: in fact, the strong asymmetry and the disturbed central region led us to consider the object as the possible product of an interaction between two galaxies.

The next table contains the results of the spectroscopic analysis of the group:

Redshift	0.013
Recessional velocity	$3.88 \times 10^3 \text{ km s}^{-1}$
Distance	53 Mpc
Velocity dispersion	274 km s^{-1}
Luminosity	$2.1 \times 10^{10} L_{\odot}$
Mass	$7.2 \times 10^{12} M_{\odot}$

These results are in agreement with the values tabulated in other catalogues, and, in particular, the velocity dispersion, luminosity, and mass values are consistent with those derived by Hickson 1982, demonstrating the accuracy of our work.

