Analysis of the luminosity of elliptical galaxies

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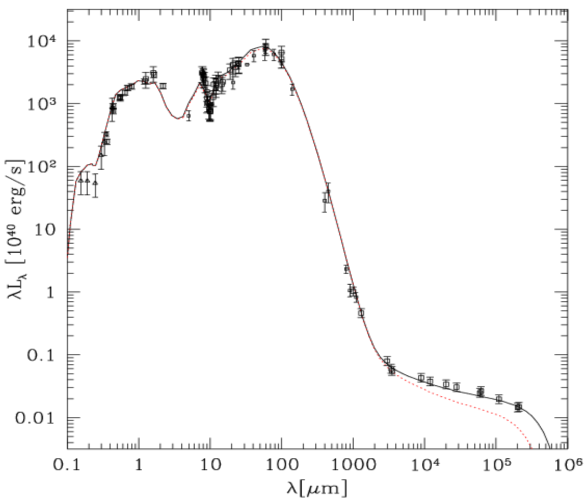
ABSTRACT

Our work was focused on the study of elliptical galaxies by means of photometric and spectroscopic data. Using a specific software, we were able to define two apparent magnitude values for each galaxy referred to two different photometric filters. With some computations we obtained the absolute magnitude values that allowed us to compare the luminosity of galaxies with that of the Sun.

I. INTRODUCTION

Magnitude is a scientific way to measure a celestial object brightness. There are two kinds of magnitudes: apparent and absolute magnitude. The first one depends on the distance between the celestial object and the observer and is related to the energy flux reaching the observer; the second one is independent of this distance set as default to 10 pc, and is related to the intrinsic energy emission called luminosity.
Dealing with galaxies, the magnitude is the sum of each star brightness value. To measure a galaxy total magnitude, we can apply the same technique used for stars, in spite of their large extension. Finally we must say that magnitude is always referred to a specific part of the electromagnetic spectrum selected by using filters, otherwise the value should be called bolometric magnitude and refer to the object whole output.



II. OBSERVATIONAL DATA

In this study, we considered only elliptical galaxies, which can be recognized according to their spectra. We selected our targets from the archive of the Sloan Digital Sky Survey (SDSS), which contains spectroscopic and photometric data of a large fraction of the sky.
After a first selection based on colour and distance (indirectly obtained from redshift), we were able to separate elliptical galaxies from the other ones looking at the presence of Hα absorption line and checking their morphology by eye.

III. WORK DESCRIPTION

After classifying the galaxies, we selected particular parameters for every single galaxy. The parameters considered in our analysis, referred to both *g* and *r* filters, are the following:
- *g and r instrumental magnitude (m_s):* extracted by the analysis of the photon counts of the image obtained through the IRAF (Image Reduction and Analysis Facility) software. With this software we drew circles of increasing radius centred on the galactic centre and we determined the total flux within each circle thanks to the fact that every pixel corresponds to a well defined photon intensity. Then, taking into account the additive sky contribution and the exposure time of the analysed images, we could calculate the total instrumental magnitude of each galaxy:

Galaxy	ms(g)	ms(r)	m0(g)	m0(r)	k (g)	k(r)	x(g)	x(r)
SDSS J080550.31+372736.2	16.689	16.069	24.452	24.093	0.188	0.100	1.070	1.077
SDSS J162754.90+403621.8	18.307	17.341	24.601	24.070	0.196	0.108	1.036	1.040
SDSS J093118.81+444647.3	17.088	16.514	24.352	24.057	0.150	0.074	1.040	1.037
SDSS J105807.60+091634.0	15.650	15.113	24.442	24.063	0.155	0.106	1.256	1.271
SDSS J161845.79+392004.0	15.889	15.284	24.348	24.044	0.149	0.085	1.076	1.083
SDSS J153215.71+092755.9	16.127	15.564	24.388	23.992	0.196	0.111	1.251	1.237
SDSS J135039.09+350217.9	15.388	14.899	24.424	24.039	0.137	0.091	1.038	1.033
SDSS J133440.34+325704.0	15.827	15.284	24.416	24.016	0.218	0.132	1.007	1.005
SDSS J122541.68+124837.8	13.975	13.565	24.481	23.999	0.194	0.096	1.115	1.122
SDSS J075638.85+440741.0	23.992	15.745	24.510	24.128	0.187	0.112	1.091	1.084
SDSS J100910.06+541331.9	24.039	15.785	24.645	24.078	0.230	0.116	1.087	1.085
SDSS J030352.91+002454.9	24.016	15.225	24.442	24.012	0.148	0.076	1.233	1.226
SDSS J141532.92+501051.7	23.999	12.115	24.566	24.046	0.184	0.122	1.189	1.199
SDSS J124622.67+115235.7	15.806	15.237	24.440	24.027	0.194	0.096	1.123	1.130
SDSS J084051.14+315853.4	16.561	16.017	24.472	24.066	0.161	0.082	0.082	1.012

$$m_s = -2.5\log\left(\frac{I - I_{sky}\cdot N_{pix}}{T_{\exp}}\right) + 25$$

where N_{px} is the number of pixel in each circle and 25 is a constant added by us to have positive magnitudes. Finally we plotted a sort of growth curve having the apparent instrumental magnitude as a function of the circle radius, and we chose the radius where magnitude became constant;

- *g_0 and r_0 magnitudes:* photometric zero-points taken directly from our SDSS database, used to convert instrumental magnitudes into calibrated magnitudes, that is photon counts into physical units;
- *g_k and r_k atmospheric extinction coefficients:* a factor that shows how much of the electromagnetic radiation coming from astronomical sources is reduced by the presence of the Earth atmosphere (absorption and scattering);
- *g_X and r_X airmasses:* values related to the angular distance of each object from the zenith. The higher is this distance the higher is the effect of atmospheric extinction.

Parameters considered up to now are necessary to calibrate the magnitude. In fact a correction to the instrumental magnitude is needed, according to the galaxy position referring to the observer's celestial horizon. Effectively this physical measurement is influenced by the presence of large dense airmasses that block part of the radiation.

To compute calibrated apparent magnitudes we used the following formula:

$$m_c = m_0 + (m_s - 25) - k\cdot X$$

where m_c and m_0 are the calibrated magnitude and the zero-point for a generic photometric band.

From the values of the calibrated magnitude of both the filters, which belong to the photometric system *ugriz*, we obtained the value of the more commonly used V magnitude by applying the formula:

$$V = g - 0.52\,(g - r) - 0.03$$

In order to obtain our final result, that is the luminosity of the galaxies, we had to calculate the absolute magnitude. This is possible by applying the Pogson's formula. As said before, apparent magnitude depends on distance, so the distance is needed and it is obtained using the redshift and the Hubble's law.

$$v = z\cdot c \qquad \Rightarrow \qquad d = (z\cdot c)/H_0$$
$$v = H_0\cdot d$$

where v is the systemic velocity of the galaxy, z is its redshift, c the speed of light and H_0 the Hubble costant. After the distance was obtained and converted into parsec, we computed absolute magnitude:

$$M_V = V + 5 - 5\log(d)$$

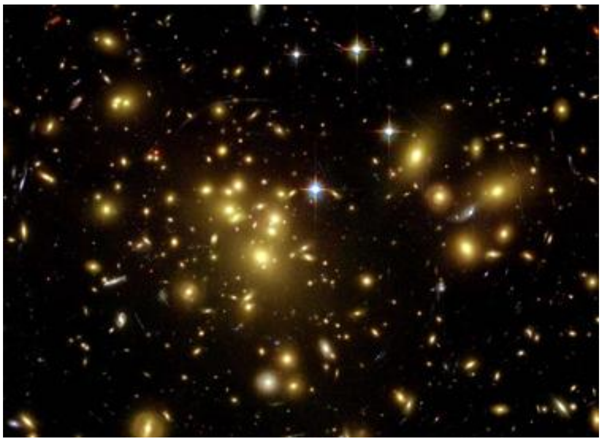
Since absolute magnitude is related to the luminosity, we used the absolute visual magnitude of the Sun ($M_V(\odot)$ = +4.72) in order to measure the luminosity of our targets in solar units:

$$L_V/L_\odot = 10^{-0.4\,(M_V - M_\odot)}$$

Galaxy	g	r	V	Redshift (z)	D (Mpc)	M(V)	L/L⊙	σ*	log σ*
SDSS J080550.31+372736.2	15.940	15.055	15.450	0.034	141.67	-20.31	1.025E+10	215.48	2.33
SDSS J162754.90+403621.8	17.705	16.299	16.944	0.033	137.50	-18.75	2.438E+09	229.96	2.36
SDSS J093118.81+444647.3	16.284	15.494	15.843	0.035	145.83	-19.98	7.560E+09	137.05	2.14
SDSS J105807.60+091634.0	14.896	14.041	14.422	0.034	141.67	-21.33	2.641E+10	324.57	2.51
SDSS J161845.79+392004.0	15.077	14.235	14.609	0.032	133.33	-21.02	1.969E+10	234.43	2.37
SDSS J153215.71+092755.9	15.270	14.419	14.797	0.033	137.50	-20.89	1.761E+10	277.47	2.44
SDSS J135039.09+350217.9	14.671	13.844	14.211	0.021	87.50	-20.50	1.224E+10	169.88	2.23
SDSS J133440.34+325704.0	15.023	14.168	14.548	0.024	100.00	-20.45	1.172E+10	184.96	2.27
SDSS J122541.68+124837.8	13.240	12.457	12.803	0.002	8.33	-16.80	4.060E+08	118.92	2.08
SDSS J075638.85+440741.0	22.915	14.752	18.640	0.047	195.83	-17.82	1.037E+09	270.59	2.43
SDSS J100910.06+541331.9	22.867	14.737	18.609	0.048	200.00	-17.90	1.113E+09	172.21	2.24
SDSS J030352.91+002454.9	22.846	14.144	18.291	0.043	179.17	-17.98	1.197E+09	304.3	2.48
SDSS J141532.92+501051.7	22.826	11.015	16.654	0.044	183.33	-19.66	5.660E+09	264.41	2.42
SDSS J124622.67+115235.7	14.615	14.156	14.346	0.044	183.33	-21.97	4.743E+10	307.71	2.49
SDSS J084051.14+315853.4	15.613	14.999	15.264	0.048	200.00	-21.24	2.423E+10	280.18	2.45

IV. RESULTS

Comparing the values of the luminosities of our targets with respect to the solar value, we observe the compatibility of the data: values of about 10^{11} $L_\odot$ are justified by the fact that elliptical galaxies are often giant galaxies made by billions of stars.



To verify the reliability of our data, we put in a graph the logarithm of stellar velocity dispersion, measured by Guglielmo, Amoruso and Colombo (see their report), which is characteristic of each galaxy, as a function of absolute magnitude. In this way we aimed to reproduce the empirical relationship published by Faber & Jackson between the luminosity and the central velocity dispersion of stars typical of elliptical galaxies:

$$L \propto \sigma^{\gamma}$$

Where γ is the gradient of the line of our graph, and should be close to 4.
Expressing this formula in logarithmic terms and using the relation between luminosity and absolute magnitude we obtain a new relation between σ and M_V:

$$\log L = \gamma \cdot \log \sigma + \text{cost}$$

$$L = L_{sun} \cdot 10^{-0.4(M - M_{sun})}$$
$$\log L = \log L_{sun} - 0.4(M - M_{sun})$$

$$\log L_{sun} - 0.4(M - M_{sun}) = \gamma \cdot \log \sigma + \text{cost}$$
$$\log \sigma = -\frac{0.4}{\gamma} M + \text{cost}$$

This is the equation of a straight line having an expected slope of about -0.1. Plotting our data and calculating the linear regression, we obtained a good correlation (r = 0.85), but the slope is equal to -0.067 which corresponds to γ about 6. This is probably due to inaccurate measurements.